JOURNAL

OF THE

AMERICAN SOCIETY OF AGRONOMY

VOLUME 37

1945

PUBLISHED BY THE SOCIETY
GENEVA, N. Y.

CONTENTS

No. 1. JANUARY

No. 2. FEBRUARY

No. 3. MARCH

No. 4. APRIL

No. 5. MAY

JOURNAL

OF THE

American Society of Agronomy

VOL. 37 JANUARY, 1945 NO. 1

RESPONSES OF PLANTS TO ADDITIONS OF MANGANESE TO SOME OREGON SOILS[1]

ALBERT W. MARSH AND WILBUR L. POWERS[2]

PRELIMINARY field and pot trials in Oregon have indicated that small applications of soluble manganese salts may result in increased yield and quality of small fruits, vegetables, and seed crops.

That small additions of a manganese salt will give increased yields and quality of crops on certain soils was shown by Aso (2),[3] Voelcher (16), Bertrand (3, 4), Skinner and Sullivan (15), and Powers (11). McHargue (8, 9) proved that traces of manganese are absolutely essential to the plant's nutrition. In purified culture solutions free from manganese, plants would grow normally for only four or five weeks, then deteriorate or fail to complete their life cycle. Various deficiency symptoms reported as being caused by a lack of available manganese have been described by Willis (18), Samuel and Piper (12), Parker, Chapman, and Southwick (10), and Sherman and Harmer (13). These diseases have usually been corrected by applying soluble manganese compounds to the plant or soil. It was for the purpose of further investigating the extent of need and the effects of manganese in some Oregon soils that this study was undertaken.

EXPERIMENTAL

The plan of experimentation was to determine by greenhouse, laboratory, and field tests if some Oregon soils, suspected of manganese deficiency, would respond to manganese additions as measured by increased crop yield, what the limits of application might be, and what the manganese level in the various plant parts would be under the different treatments.

Manganese was determined colorimetrically in plant material and soil extracts by the potassium periodate method of Willard and Greathouse (17), and the resulting color read in a Klett-Summer-

[1]Published as Technical Paper No. 415 with the approval of the Director of the Oregon Agricultural Experiment Station, Oregon State College, Corvallis, Ore., as a contibution of the Soils Department. Received for publication July 10, 1944.

[2]Formerly Research Assistant in Soils, now Assistant Irrigation Engineer, and Soil Scientist, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 7.

son photoelectric colorimeter using a 540 millimicron green filter. Reagent blanks were carried along with each set of determinations. Plant material was oxidized in the muffle furnace at 600° C.

Available manganese in soils was considered as being the sum of the water-soluble and exchangeable manganese. The easily reducible manganic oxide was shown by Leeper in 1935 (7) to be slowly available to plants and is extracted by neutral, normal ammonium acetate containing 0.2% hydroquinone after the water-soluble and exchangeable manganese have been removed. Active manganese is the sum of the water-soluble and exchangeable manganese plus the easily reducible manganic oxide (14). Total manganese was determined by an alkali fusion followed by the Volhard titration if large amounts were present. For smaller amounts the colorimetric method was used.

INVESTIGATIONS WITH KLAMATH AND LABISH PEAT

Preliminary investigations by Powers (11) indicated that manganese improved the yield and crop quality when applied to peat land. Surface samples of a basic tule-sedge peat from Klamath and a moderately acid willow-sedge peat from Lake Labish were obtained and potted in 2-gallon glazed jars so that there were 28 jars of each soil. The soils were fertilized as shown in Table 1 in groups of four. Two groups were used to give the NPK check. All except the blank check received pure chemicals in solution equivalent to 1,000 pounds per acre of 4–12–8 mixture. Sugar beets were seeded in three pots from each treatment, the fourth was left fallow. After germination, the beets were thinned to four per pot and grown all

TABLE 1.—*Yield and manganese content of sugar beets grown in Klamath and Labish peats in the greenhouse.*

Treatments	Rate per acre, lbs.	Yield*		Manganese content	
		Average per jar, grams	Relative to NPK, %	Leaves, p.p.m.	Roots, p.p.m.
		Klamath Peat			
Blank check.....	—	184.7	91.8	52.7	23.5
NPK check......	—	204.0			
NPK check......	—	198.2	100.0	42.5	20.3
NPK, $MnSO_4$....	10	218.9	109.0	56.2	22.5
NPK, $MnSO_4$....	40	224.8	112.0	76.0	30.3
NPK, $MnSO_4$....	80	235.7	117.2	161.5	34.2
NPK, $MnSO_4$....	160	212.0	105.5	109.5	41.7
		Labish Peat			
Blank check.....	—	51.9	69.5	538	130
NPK check......	—	64.8			
NPK check......	—	84.5	100.0	570	160
NPK, $MnSO_4$....	10	87.4	117.0	548	91
NPK, $MnSO_4$....	40	86.1	115.5	553	164
NPK, $MnSO_4$....	80	61.3	82.2	495	129
NPK, $MnSO_4$....	160	67.8	90.8	667	172

*Statistical analyses of yield data: Klamath peat, F = 3.43; number required for significance between means = 49.4 grams. Labish peat, F = 7.15; significance between means = 28.0 grams.

winter in the greenhouse. When harvested they were topped, the roots weighed, and the parts dried for analysis. Table 1 shows the yield and manganese content of the beets.

On Klamath peat the yield rises slightly until the 160-pound treatment is reached, at which point it falls off. On Labish peat slight increases resulted from the 10- and 40-pound applications, but a decrease resulted from the two larger treatments. The manganese content of the leaves and roots indicate that the Labish peat is much more abundantly supplied with available manganese than the Klamath peat.

The soil in the uncropped pots adjacent to the cropped jars was maintained approximately at field moisture capacity. Ten months after treatment, samples were taken from all fallow pots and analyzed for exchangeable and easily reducible manganese. Total manganese was determined on the check sample of each soil. These results, reported in Table 2, conform with those obtained by the previous analysis of the sugar beet leaves. They show that the slightly basic Klamath peat is low in both active and total manganese, while the acid Labish peat has an ample supply of active manganese as well as a relatively large total. The figures for active manganese show that with both soils, except the 40-pound application on Klamath peat, the greater part of the added manganese was fixed so that even the hydroquinone solution did not extract it. In treating these peat soils 1,000,000 pounds were used as the weight per acre.

TABLE 2.—*Comparison of exchangeable manganese and easily reducible manganese in Klamath and Lake Labish peats.*

Treatment	Rate per acre, lbs.	Exch. Mn, p.p.m.	Easily reducible manganic Mn, p.p.m.	Active Mn, p.p.m.*	Total Mn, p.p.m.
		Klamath Peat			
Check	—	9.1	6.1	15.2	205
NPK	—	4.8	8.0	12.8	—
NPK, $MnSO_4$	10	5.6	7.0	12.6	—
NPK, $MnSO_4$	40	26.9	15.5	42.4	—
NPK, $MnSO_4$	80	10.2	12.5	22.7	—
NPK, $MnSO_4$	160	9.0	13.9	22.8	—
		Labish Peat			
Check	—	17.0	146	163	1,350
NPK	—	21.0	152	173	—
NPK, $MnSO_4$	10	22.7	144	167	—
NPK, $MnSO_4$	40	16.7	157	174	—
NPK, $MnSO_4$	80	18.2	156	174	—
NPK, $MnSO_4$	160	19.4	158	177	—

*Sum of the exchangeable and easily reducible manganese. Water-soluble manganese never exceeded a trace.

INVESTIGATIONS WITH CLATSKANIE PEAT

A moderately acid sedge muck from Clatskanie was potted in 1-gallon glazed jars, each containing 1,640 grams of dry soil. This was fertilized with pure chemicals in solution as indicated in Table 3,

except the lime, which was applied as pure precipitated chalk at the rate of 2 tons per acre. The NPK pots received 1,000 pounds per acre of 4–12–8 plus 0.5 p.p.m. of boron.

TABLE 3.—*Yield and manganese content of beans grown on Clatskanie peat in the greenhouse.*

Treatment	Rate per acre, lbs.	Average yield per jar		Manganese content	
		Total dry matter	Relative to NPK, %	Leaves, p.p.m.	Beans, p.p.m.
		First Crop*			
Check	—	8.3	95.5	166	28.7
NPK, Ca	—	8.7	100.0	131	29.1
NPK, Ca $MnSO_4$	40	9.5	109.2	172	24.4
NPK, Ca $MnSO_4$	80	8.2	94.2	288	32.3
NPK, Ca $MnSO_4$	160	6.1	69.5	—	38.7
NPK, Ca $MnSO_4$	240	6.7	77.0	640	38.3
NPK, Ca $MnSO_4$	320	8.8	100.6	577	35.1
NPK, (–Ca) $MnSO_4$	80	8.2	94.2	390	40.0
		Second Crop*			
Check	—	12.8	78.5	60.5	25.4
NPK, Ca	—	16.3	100.0	57.0	19.2
NPK, Ca $MnSO_4$	40	15.8	96.9	88.0	18.7
NPK, Ca $MnSO_4$	80	16.1	98.8	74.0	22.5
NPK, Ca $MnSO_4$	160	18.7	114.8	79.0	22.6
NPK, Ca $MnSO_4$	240	19.6	120.3	61.0	26.1
NPK, Ca $MnSO_4$	320	18.2	111.7	74.0	35.3
NPK, (–Ca) $MnSO_4$	80	16.9	103.6	104.0	29.1

*First crop grown December 9, 1940, to February 5, 1941; second crop grown February 8, 1941 to April 22, 1941.

The first crop of beans which was grown during December and January made a rather small growth and absorbed ample quantities of manganese, as can be seen from the manganese content of the leaves. There was no particular increase in yield from manganese treated pots, and in some cases a distinct decrease occurred.

A second crop of beans was grown in February, March, and April, with retreatment of manganese at the same rates. As shown in Table 3, an increase in yield was obtained from the manganese-treated pots except the two lighter applications. In these two trials, as in the trials with Klamath and Labish peats, there is an indication that when the manganese content of the leaves is less than 100 p.p.m., increased yields may be obtained by adding manganese, while no particular increase or even decreases in yield may result when the manganese content exceeds 100 p.p.m.

With both crops it is evident that of the two groups of pots which did not receive manganese, the leaves absorbed more manganese from the one which did not receive lime. The same relationship holds true for the groups which received an application of 80 pounds per acre of manganese sulfate. This agrees with the findings of Allison, *et al.* (1) on calcareous Florida peats, with Gilbert and McLean (5) on over-limed soils in Rhode Island, and with Willis (19) on over-

limed and naturally calcareous soils of North Carolina. They found that a high lime content may cause manganese deficiency resulting in chlorotic plants.

After harvesting, soil samples were taken from all jars, the like treatments combined and mixed, and extractions for the various forms of manganese made. The results are reported in Table 4.

TABLE 4.—*Manganese in Clatskanie peat after harvests.*

Treatment	Rate per acre, lbs.	Water-soluble Mn, p.p.m.	Exchangeable Mn, p.p.m.	Easily reducible manganic Mn, p.p.m.	Total active Mn, p.p.m.
NPK, Ca...........	—	0	17.2	69	86.2
NPK, Ca $MnSO_4$....	40	0	13.9	104	117.9
NPK, Ca $MnSO_4$....	80	0	20.8	170	190.8
NPK, Ca $MnSO_4$....	240	Trace	24.5	187	211.5
NPK, (–Ca) $MnSO_4$	80	0	51.9	98	149.9

Water-soluble manganese is negligible in all treatments. The exchangeable manganese is highest with the unlimed treatment being more than twice that of the same manganese application when lime had also been added. Conversely, the unlimed soil has less easily reducible manganic oxide than any other except the control. The lime, evidently, displaces a large portion of the manganese from the exchange complex after which it is oxidized to a form which is more difficultly available.

INVESTIGATIONS WITH BRAILLIER PEAT

In a further study of organic soils, a coarse, fibrous, mossy-peat of acid reaction was obtained from Braillier marsh near Astoria.

This peat is formed in low marshes along the lower Columbia River and is subject to flooding during parts of the year. At this time manganese is reduced to the soluble form. With drainage most of the soluble manganese is leached away. When the peat dries out in the summer, good oxidizing conditions are brought about because of its open structure, and the manganese remaining is oxidized and made difficultly available.

This peat was duplicated in 2-gallon glazed jars, each containing 1,360 grams of dry material. All jars received fertilizers as pure chemicals in solution equivalent to 1,500 pounds per acre of 0–16–24, in addition to 4 tons of lime. Manganese sulfate was applied as shown in Table 5.

Lotus corniculatus was seeded in October 1941, the soil inoculated, and growth continued until April 1942, with the aid of supplemental illumination during the winter months. A second cutting was harvested in July. The yield data are presented in Table 5.

Manganese applications gave slight to moderate increases over the check, but there was no increased benefit in using rates higher than 20 pounds per acre. On an acid peat of such open structure, a small application is sufficient, and a heavy application might be initially toxic.

TABLE 5.—*Response of lotus to manganese on Braillier peat in the greenhouse.*

Treatment	Rate per acre, lbs.	First cutting		Second cutting	
		Average per jar, grams	Relation to NPK, %	Average per jar, grams	Relation to NPK, %
NPK..........	—	18.3	100	21.7	100
NPK, $MnSO_4$..	20	22.7	124	25.9	119
NPK, $MnSO_4$.	40	19.2	105	23.2	107
NPK, $MnSO_4$..	80	20.0	109	26.3	121
NPK, $MnSO_4$..	160	20.0	109	23.9	110

Certain disorders have been noted on the leaves of small fruit grown on Olympic clay loam. A sample of this soil was taken from a check plot on a cooperator's farm and all forms of active manganese determined by the usual extractions. The following results were obtained: water-soluble Mn, 9.2 p.p.m.; exchangeable Mn, 115 p.p.m.; easily reducible manganic Mn, 1,202 p.p.m.; and total active Mn, 1,326 p.p.m.

The active manganese in this soil is thus found to be very high. This high content of manganese may possibly be connected with the leaf disorders. Further study is in progress on this problem.

RESULTS FROM FIELD TRIALS

Various field trials have been carried on by the authors and by cooperating agencies during the last few years. Manganese sulfate was applied at rates varying from 10 to 60 pounds per acre.

On Chehalis silty clay loam a Latin square minor elements trial has been conducted for 3 years with table beets. There were eight treatments and eight replications. Manganese sulfate was applied at 40 pounds per acre each year. The results are shown in Table 6. A significant increase in yield was obtained the first year when the general fertility level was low, but since then the increases have been small and not statistically significant.

TABLE 6.—*Response of beets to manganese sulfate on Chehalis silty clay loam, Latin square trial.*

Year	Yield per acre, tons			Standard error of difference	Significance
	Check	Manganese	Difference		
1941	4.47	5.96	1.49	0.44	Yes
1942	8.14	8.52	0.38	0.49	No
1943	11.30	11.72	0.42	0.32	No

Manganese sulfate has been applied at 20, 40, and 60 pounds per acre to corn and barley on Willamette silty clay loam since 1941. Yields have not differed significantly from the check plot averages. With increased rate of application in the corn trials, the data show a

slight trend toward increases in yield, while with barley the reverse effect was apparent.

Field trials with farmer cooperators were also carried out on several different soil types. These trials included boysenberries on Willamette silt loam, beets on Newberg sandy loam, blackcaps on Olympic clay loam, raspberries and beans on Powell silt loam, and beans and tomatoes on Chehalis silty clay loam. In none of these trials, which were on acid to nearly neutral mineral soils, was there any consistent response to added manganese sulfate, and in a few cases negative responses were noted.

DISCUSSION AND CONCLUSIONS

The soils studied in this paper that showed a need for manganese occupy a small proportion of the total cultivated land in Oregon. Those soils that need manganese are not widespread and the deficiencies that do exist are not acute as crops grown on them do not show severe disease or deficiency symptoms. Manganese has induced certain increases in yield and quality of crops from some peat soils which make its use desirable under intensive cultivation. These are the basic peats and a coarse acid peat alternately submerged and desiccated. Acid peats and mineral soils are not likely to respond.

The peat soils, except Braillier peat, have a rather high manganese fixation capacity so that relatively large applications could be made without toxic effects. On the basis of yields obtained and the amount remaining available in the soil it would be more feasible to make moderate applications yearly.

In the plant leaves analyzed the manganese level varied from 40 to nearly 700 p.p.m., in the other plant parts from 20 to 170 p.p.m. An indication is provided of response to manganese when the leaf content is less than 100 p.p.m. No distinct disease symptoms appeared at the 40 p.p.m. level though it was thought to be near the borderline. Gilbert, *et al.* (6) found that the manganese requirement of oats and spinach was 20 to 60 p.p.m.

In the soil active manganese varied from 12 to 1,326 p.p.m. These extremes probably are in the range of deficiency and toxicity. The degree of responses did not associate well with any definite level probably because of other factors in the soil.

Soils containing an excess of active manganese with all its physicochemical and physiologic reactions may be found in some of the residual hill lands.

LITERATURE CITED

1. ALLISON, R. V., BYRON, O. C., AND HUNTER, J. H. The stimulation of plant response on the raw peat soils of the Florida everglades through the use of copper sulfate and other chemicals. Fla. Agr. Exp. Sta. Bul. 190. 1927.
2. ASO, K. On the practical application of manganous chloride in rice culture. Bul. Col. Agr., Tokyo, 6:131–133. 1904.
3. BERTRAND, G. Sur L'emploi favorable du manganese comme engreis. Comptes Rendus, 141:1255–1257. 1905.
4. ———. Manganese as a catalytic fertilizer. Orig. Com. 8th Int. Congr. Appl. Chem., 15:39. 1912.

5. GILBERT, B. E., AND MCLEAN, F. T. A deficiency disease: The lack of available manganese in a lime induced chlorosis. Soil Sci., 26:27–31. 1928.
6. ———, ———, AND HARDIN, L. J. The relation of manganese and iron to a lime induced chlorosis. Soil Sci., 22:437–446. 1926.
7. LEEPER, G. W. Manganese deficiency of cereals, plot experiments and a new hypothesis. Proc. Roy. Soc. Victoria, 47, 11:225–261. 1935.
8. MCHARGUE, J. S. The role of manganese in plants. Jour. Amer. Chem. Soc., 44:1592–1598. 1922.
9. ———. Effect of different concentrations of manganese sulfate on the growth of plants in acid and neutral soils and the necessity of manganese as a plant nutrient. Jour. Agr. Res., 24:781–793. 1923.
10. PARKER, E. R., CHAPMAN, H. D., AND SOUTHWICK, R. W. Manganese deficiency for citrus in California. Science, 91:169–170. 1940.
11. POWERS, W. L. Chemical characteristics of peat and muck soils in northwestern United States. 2d Int. Congr. Soil Sci., 6:246–256. 1930.
12. SAMUEL, G., AND PIPER, C. S. Grey speck disease of oats. Jour. Dept. Agr. South Australia, 31:696–705. 1928.
13. SHERMAN, G. D., AND HARMER, P. M. Manganese deficiency of oats on alkaline organic soils. Jour. Amer. Soc. Agron., 33:1080–1092. 1941.
14. ———, MCHARGUE, J. S., AND HODGKISS, W. S. Determination of active manganese in soil. Soil Sci., 54:253–257. 1942.
15. SKINNER, J. J., AND SULLIVAN, M. X. Action of manganese in soils. U.S.D.A. Bul. 42. 1914.
16. VOELCHER. Pot culture experiments. Jour. Royal Agr. Soc., London, 64: 348–364. 1904.
17. WILLARD, H. H., AND GREATHOUSE, L. H. The colorimetric determination of manganese by oxidation with periodate. Jour. Amer. Chem. Soc., 39:2366–2377. 1917.
18. WILLIS, L. G. Response of oats and soybeans to manganese on some coastal plain soils. N. C. Agr. Exp. Sta. Bul. 257. 1928.
19. ———. The effect of liming the soils on the availability of manganese and iron. Jour. Amer. Soc. Agron., 24:716–726. 1932.

YIELD-DEPRESSION EFFECT OF FERTILIZERS AND ITS MEASUREMENT: II. REPORT ON NUTRITIONAL UNBALANCE DISCLOSED BY FIELD TESTS[1]

O. W. WILLCOX[2]

THE subject of yield-depression by plant nutrients has been previously treated by the writer (5).[3] Briefly, it is found (2) that when a crop is planted in an otherwise *normal* soil deficient in a particular plant nutrient and is then treated with graded increments of that nutrient, the resulting yield curve will conform with the regular Mitscherlich-Baule yield equation; *provided*, that addition of the nutrient is not carried to the point of causing nutritional unbalance. In the latter case the yield curve will branch off on a different course that is determined by a coefficient, k, which measures the degree of nutritional unbalance. Where nutritional unbalance has thus been created, the whole yield curve is seen to be composed of two limbs, a lower limb that conforms with the normal yield equation $y = A\ (1\text{-}10^{-0.301x})$ and an upper limb that answers to the depression equation $y = A\ (1\text{-}10^{-0.301x}).10^{-kx^2}$ which is the normal M.-B. yield equation modified by a depression constant k, the magnitude of which is dependent on the surrounding circumstances. In these equations y is the obtained yield, A the maximum possible yield, and x the total amount of the nutrient in the soil. The numeral 0.301 is the normal effect factor of any growth factor when the amount of this factor, x, is stated in Baule units (baules).

In the previous paper the standard yield diagram was employed as a convenient means of demonstrating the depression-effect of nitrogen in field tests with corn, tea bushes, sugar cane, and sugar beets. In the meantime the study has been extended to a wide range of published field tests with various crops and fertilizers in the United States and abroad. The large proportion of cases where the yield curves have been found to exhibit the dual character of normality and depression shows that nutritional unbalance is imposing severe limits on productive agriculture. In view of the wide prevalence of the phenomenon, and its obvious agronomic importance, some examples of what has been found in this survey are given.

The term "yield depression" as here employed has been questioned. In the first three examples all the treatments have produced successive increases, and apparently there has been no depression. What is meant is that the increases should continue at the rate established by the lower normal limb of the curve; what happens is that, due to physiologic unbalance, the higher increments of fertilizer give increases at a rate less than the normal rate. With any given amount of fertilizer, the spread between the extension of the normal curve and the actual curve measures the deficiency from the normal yield; in other words, this spread measures the amount of additional yield that should have been obtained.

[1]Received for publication July 19, 1944.
[2]Consulting Agrobiologist, 197 Union St., Ridgewood, N. J.
[3]Figures in parenthesis refer to "Literature Cited", p. 20.

As a first example reference is made to a report by Rogers (3) concerning the use of sodium nitrate on seed cotton, oats, and corn. This work was a 3-year project on a number of farms located on various types of soil in South Carolina. The essential field data are set forth in Table 1, together with the necessary recalculations to fit the data in the standard yield diagram. The average results of the whole work are diagrammed in Fig. 1. For convenience, the yields of seed cotton are graphed in units of 200 pounds, of oats in 12 bushels, and of corn in 8 bushels. From the diagram it is immediately seen that all these crops have reacted normally to the lower additions of nitrogen, while the higher increments have depressed the yields. With seed cotton (upper curve) the yields from the first three in-

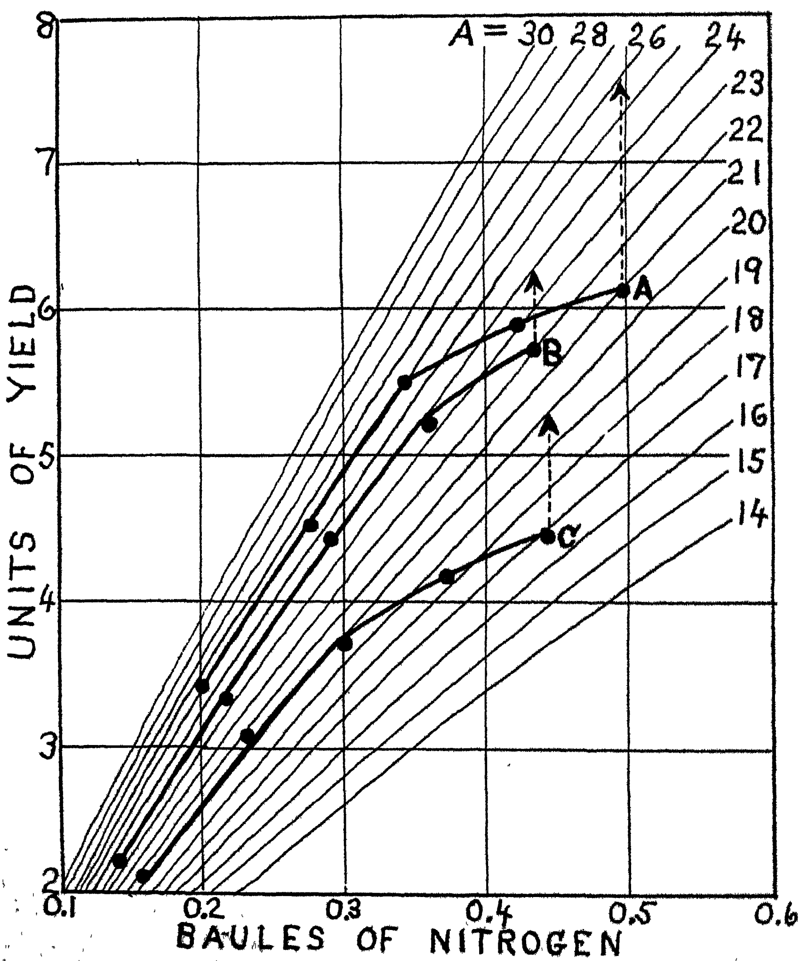

FIG. 1.—Standard yield diagram of Rogers' field test with sodium nitrate on *A*, seed cotton; *B*, oats, and *C*, corn.

TABLE 1.—*Rogers' field test with sodium nitrate on seed cotton, oats, and corn.*

Sodium nitrate, lbs. per acre I	Equivalent baules of nitrogen* II	Total nitrogen in soil, baules† III	Yields: Reported, lbs. per acre for seed cotton and bu. per acre for oats and corn IV	Yields: Reduced to, units of 200 lbs. for seed cotton, 12 bu. for oats, and 8 bu. for corn V	Yields: Calculated by Depression equation VI	Yields: Calculated by Normal equation VII	Values of k VIII	Depression effect in % of normal IX
Seed Cotton, 3-year Averages from 15 Farms								
0	0	0.203	681	3.40	3.41	3.41	—	—
100	0.072	0.276	903	4.51	4.57	4.51	—	—
200	0.143	0.340	1,104	5.52	5.52	5.52	—	—
300	0.215	0.422	1,180	5.90	5.77	6.59	0.269	10.4
400	0.287	0.499	1;225	6.12	6.29	7.60	0.376	19.4
							0.322	
Oats, 3-year Averages from 18 Farms								
0	0	0.144	26.4	2.20	2.18	2.21	—	—
100	0.072	0.218	39.9	3.32	3.32	3.35	—	—
200	0.143	0.290	53.4	4.45	4.45	4.40	—	—
300	0.215	0.360	62.4	5.20	5.28	5.21	—	—
400	0.287	0.432	68.8	5.73	5.73	6.21	0.267	7.7
Corn, 3-year Averages from 18 Farms								
0	0	0.157	17.0	2.10	2.15	2.15	—	—
100	0.072	0.231	24.6	3.07	3.09	3.07	—	—
200	0.143	0.303	29.7	3.70	3.68	3.68	—	—
300	0.215	0.373	33.5	4.18	4.18	4.56	0.272	8.3
400	0.287	0.445	35.7	4.46	4.71	5.34	0.394	16.4
							0.333	

*A baule of nitrogen is 223 pounds on an acre basis.
†Original soil nitrogen plus added nitrogen.

crements of nitrogen make an excellent fit on curve A = 26, which means that if the average nutritional set-up existing on these cotton fields after inclusion of the first three increments of nitrogen could be projected forward, these fields could produce an ultimate maximum yield of 26 × 200 = 5,200 pounds of seed cotton, or somewhat more than 3 bales of lint. But it is plain that the higher additions of nitrogen have thrown this nutrient out of balance with the original factors. Beyond the third addition of nitrogen yield-depression intervened, and at the fifth addition, the yield was 6.12 units instead of the 7.60 units predictable by the normal yield equation and indicated by the arrow reaching to curve 26. The indicated yield depression (unobtained yield) amounts to 19.4%, figured on the normal expectancy from 400 pounds of sodium nitrate. The depression factors k found for the three crops are shown in column VIII of Table 1.

With these k factors we can write the following equations for Rogers' results:

$$\begin{aligned}
\text{Yield of seed cotton} &= 26\,(1 - 10^{-0.301x}).10^{-0.322x^2}\\
\text{Yield of oats} &= 24\,(1 - 10^{-0.301x}).10^{-0.267x^2}\\
\text{Yield of corn} &= 20\,(1 - 10^{-0.301x}).10^{-0.333x^2}
\end{aligned}$$

The agreement between the observed and calculated yields is good (columns V and VI).

A second example is an 11-year test on rate and time of application of potash to seed cotton on Norfolk sand at the Sandhill Experiment Station in South Carolina. The field data, shown in Table 2 and Fig. 2, were kindly supplied by Prof. W. H. Garman. The work embraced three operational variants, *viz.*, all potash before planting, all at chopping, and half before planting and half at chopping. All three of the resulting yield curves have normal and depression limbs. The average values of k for the three operational variants are, respectively, 0.057, 0.0717, and 0.0854. These values of k are much smaller than those found for nitrogen in Rogers' work, which accords with the general observation that yield depression is more severe with an excess of nitrogen than with an excess of potash. Still, the depressive effect of potash on these soils is on the whole considerable. Thus, in the variant where half the potash was applied before planting and half at chopping (upper curve, Fig. 2) the normal expectancy from 60 pounds of potash was 10.75 yield units, whereas 8.92 units were obtained. In this phase of the test, if the nutritional set-up after inclusion of the first three increments of potash were projected forward on curve 22 without unbalance, there would be produced an ultimate maximum yield of 22 × 200 = 4,400 pounds of seed cotton. Particular attention may be directed to the small difference between the yields from the three experimental variants at all levels of potash. Thus, the end results are represented by harvests of 1,450, 1,470, and 1,485 pounds per acre. The maximum spread between the three curves is 37 pounds, yet there is no overlapping of the three curves at any level which is an impressive testimony of the accuracy that can be attained in a carefully conducted, long term regional field test.

A third example is taken from data compiled by Bray (1) on the relation between available soil potassium and yields of corn, soy-

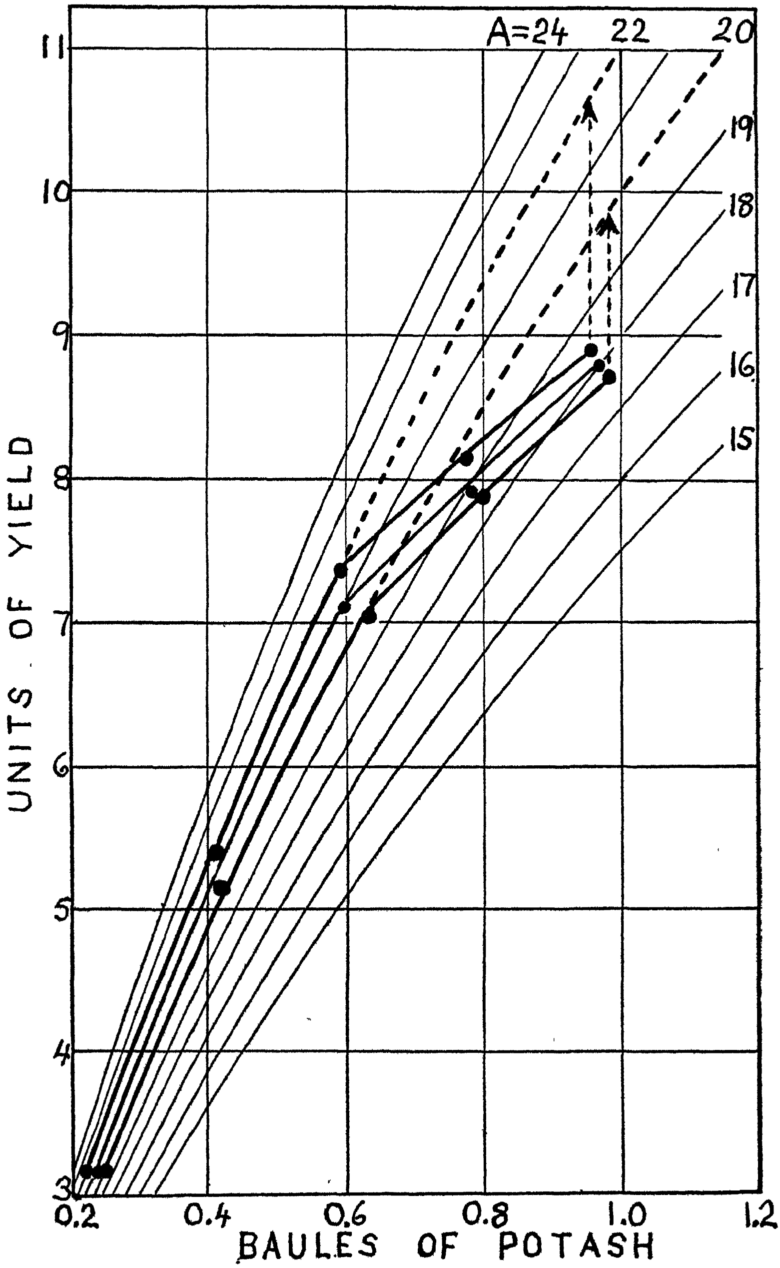

Fig. 2.—Standard yield diagram of test on time and rate of application of potash to seed cotton. Upper curve, half before planting and half at chopping; middle curve, all at chopping; lower curve, all before planting.

TABLE 2.—*Yield of seed cotton from an experiment on rate and time of applying potash.**

Potash, lbs. per acre	Equivalent baules of potash†	Total potash in soil, baules‡	Yields				Values of k	Depression effect in % of normal
			Reported, lbs. per acre	Reduced to units of 200 lbs.	Calculated by			
					Depression equation	Normal equation		
I	II	III	IV	V	VI	VII	VIII	IX
			All Before Planting					
0	0	0.252	529	3.17	3.17	3.17	—	—
15	0.182	0.414	863	5.18	5.18	5.18	—	—
30	0.365	0.619	1,173	7.04	7.04	7.04	—	—
45	0.548	0.800	1,314	7.88	7.85	8.55	0.0553	7.8
60	0.731	0.984	1,450	8.70	8.72	9.96	0.0599	12.5
							0.057	
			All at Chopping					
0	0	0.230	529	3.17	3.09	3.09	—	—
30	0.365	0.598	1,117	7.06	7.12	7.12	—	—
45	0.548	0.785	1,321	7.92	7.94	8.80	0.0741	10.0
60	0.731	0.964	1,470	8.82	8.87	10.23	0.0693	13.7
							0.071	
			One-half Before Planting, One-half at Chopping					
0	0	0.222	529	3.17	3.17	3.17	—	—
15	0.182	0.414	923	5.54	5.54	5.54	—	—
30	0.365	0.598	1,228	7.37	6.93	7.50	—	—
45	0.548	0.778	1,355	8.13	8.25	9.20	0.0883	11.6
60	0.731	0.966	1,487	8.92	8.95	10.75	0.0825	16.9
							0.0854	

*From field data supplied by W. H. Garman, Clemson Agricultural College, Clemson, S. C.
†A baule of potash is 82 pounds on an acre basis.
‡Original potash plus added potash.

beans, and wheat on 23 farms in Illinois. By available potassium Bray understands exchangeable potassium as determined in soil analyses. He found that the maximum yield of corn was obtained when the soil contained 236 pounds of available potassium per acre; the maximum yield of soybeans coincided with 182 pounds per acre, and the maximum yield of wheat with 127 pounds per acre of available potassium. With less potassium the yields of each crop were smaller. From these relations, and taking the observed maximum yields as percentage bases, Bray compiled a table showing how much potassium is needed to produce a named percentage of the maximum

TABLE 3.—*Relation between soil potassium and percentage yields of corn, soybeans, and wheat in Illinois.*

Available exchangeable potassium, lbs. per acre	Equivalent baules of K*	Total baules of K†	Yields, % of Bray's maximum			Values of k.	Depression effect in % of normal
			Observed	Calculated by			
				Depression equation	Normal equation		
I [1]	II	III	IV	V	VI	VII	VIII
			Corn				
55	0.808	0.88	53	53.1	53.1	—	—
73	1.072	1.15	63	63.1	63.1	—	—
95	1.395	1.47	74	73.9	73.9	—	—
109	1.601	1.68	79	79.6	79.6	—	—
127	1.895	1.97	84	84.3	86.0	—	—
150	2.203	2.28	90	90.8	91.0	0.00092	1.1
182	2.674	2.75	95	95.0	98.0	0.00172	3.1
236	3.467	3.55	100	100.8	105.0	0.00169	4.0
						0.00144	
			Soybeans				
55	0.808	0.88	65	65.0	65.0	—	—
73	1.072	1.15	77	77.0	77.0	—	—
95	1.395	1.47	85	85.1	89.5	0.0072	4.9
109	1.601	1.68	89	90.4	96.6	0.0138	7.8
127	1.895	1.97	94	95.2	104.5	0.0130	10.0
150	2.203	2.28	98	98.1	111.5	0.0112	14.8
182	2.674	2.75	100	99.4	119.5	0.0110	19.5
						0.0112	
			Wheat				
55	0.808	1.35	79	78.8	79.0	—	—
73	1.072	1.60	87	87.3	87.0	—	—
95	1.395	1.91	96	96.2	96.0	—	—
109	1.601	2.15	98	97.6	101.0	0.0028	2.9
127	1.895	2.40	100	100.6	105.8	0.0036	5.8
						0.0032	

*One baule of potassium (K) is 68.06 pounds.
†Exchangeable plus nonexchangeable K.

yield of each of these three crops. This table, which is incorporated in Table 3 (columns I and IV), is currently used in making recommendations as to the potash requirements of Illinois farms on the basis of tests on farmers' soil samples. In compiling his table Bray could not reconcile his data with the M.-B. system, which specifies that a given amount of soil potassium (e.g. 1 baule) will produce the same percentage of the maximum crop of any plant, whereas it appeared, and was indeed a fact, that on these Illinois soils different crops required different amounts of potassium to produce the same percentages of their observed maximum yields.

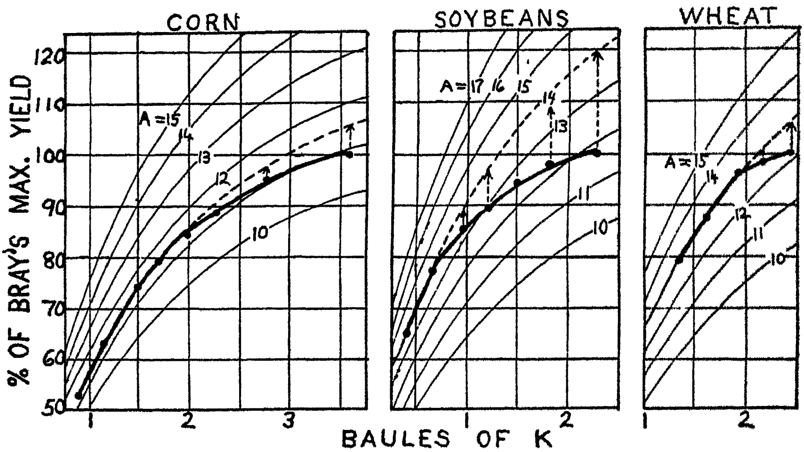

FIG. 3.—Standard yield diagram of relations between soil potassium (K) and yields of corn, soybeans, and wheat. Field data from Bray.

However, when graphed on the standard yield diagram, (Fig. 3), Bray's data are seen to conform in every respect with the M.-B. system, which expresses the whole action of a factor of plant growth in both of its functions—as a growth-promoter, and as a growth-depressor. The first of these functions is mathematically expressed by the normal M.-B. yield equation $y = A(1 - 10^{-0.0301x})$ which holds only when x is not in physiologic excess. When x is in excess the normal yield equation naturally will not hold. Then the depression equation, which is merely the normal equation qualified by a depression constant k, takes over (2). Much of the difficulty experienced by some agronomists and plant biochemists in their struggles with the M.-B. system seems to be due to the unsuspected presence of nutritional unbalance in their experimental data.

At all events, the behaviors of corn, soybeans, and wheat towards potash on these Illinois farms might well serve as classic examples of the applicability of both the normal and the depression equations. In the case of corn the yields from the four lower increments of potash conform as closely as could be desired with the normal yield equation wherein $A = 11.5$, while the whole curve is very closely defined by the depression equation wherein k has the average value

0.00144. Similar concordance of the calculated and the observed yields of soybeans and wheat is apparent (columns IV and V, Table 3).

The positions of the initial yield points above the horizontal axes indicate that Bray's corn and soybeans soils had each an original 0.88 baule of exchangeable K, while the diagram credits the wheat soil with an original 1.35 baules. All the crops were grown in rotation on the same soils. A reason why more available K should show up in the wheat rotation remains to be sought.

DISCUSSION

The original manuscript of this paper was reviewed by a number of persons who have offered some suggestions; one is that the standard yield diagram should be made to fit four or five data points instead of only two or three. If this were done the depression factor would not be given nearly as much weight, and the *A* values, from which the depression effect is measured, would not be so high.

This suggestion implies that the standard yield diagram is a plastic thing that may twisted as desired. If that were so, the diagram would have no scientific or practical value. The diagram is, in fact, as inflexible as the *normal* M.-B. equation on which it is based. This equation is characterized exclusively by the single factor 0.301, which, in the M.-B. system, is held to apply to all kinds of plants that are grown under *normal* conditions, and to all plant nutrients when these are present in agrobiologic balance. No yield curve or part of a yield curve which does not answer to this constant is to be considered as a correct representation of *normal* plant yields. In the mechanic arts or elsewhere in daily life there would be no sense in having a standard foot rule that could be lengthened or shortened to fit discordant situations. There will also be no sense in having a standard of agrobiologic *normality* that could be altered to give a false appearance of *normality* to aberrant phenomena. Exactly what the practice of plant nutrition now needs to make it a real science is an authentic pattern of normality, by which abnormality may be recognized and assessed.

The variation of the value of *k* with different kinds of plants and soils has seemed to be hard for some to understand. The value of *k* depends entirely on known or unknown soil conditions inimical to *normal* crop yields. Some crops may or may not be more susceptible to the same hostile factor than another; the diagram merely measures the depressive effect, without reference to the cause or the kind of plant.

In one opinion, the claim that deficiencies other than the fertilizers in use are not permitting these fertilizers to function fully has been challenged as an unproved assumption. The cited examples of field results from South Carolina and Illinois indeed do not bring direct proof that the depression curves might come closer to normality if missing factors responsible for the unbalance are supplied. But such proof is available in other examples. In deference to the current shortage of space only one will be cited.

This example is an experiment by Wellington and Collison (4) with nitrogen and potash on Concord grapes in New York State. The field data will be found in Table 1 of the original paper for the 1941 and 1942 crops. Briefly, there were five treatments, no N; 32 pounds N; 64 pounds N; 96 pounds N; and 64 pounds N, and 100 pounds K. The standard yield diagram of this experiment is shown in Fig. 4. Yield units for diagramming were obtained by dividing the reported pounds of grapes per acre in the 1941 crop by 500; for the 1942 crop the divisor was 1,000.

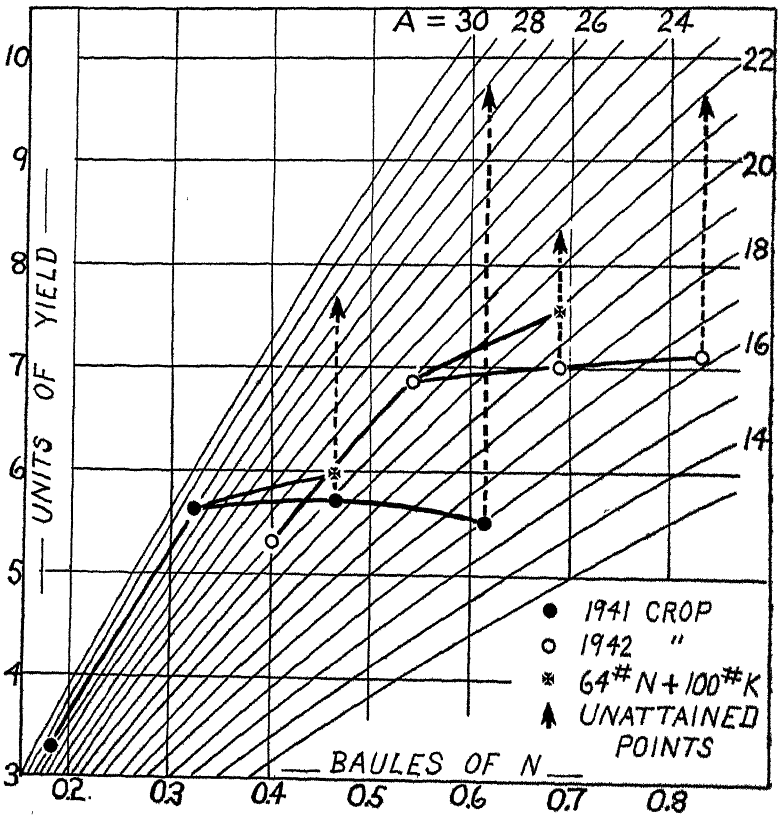

FIG. 4.—Wellington and Collison's field experiment with nitrogen on grapes.

In 1941 the two treatments no N and 32 pounds N define A = 28 as the normal yield curve. That is, the indicated maximum possible yield for N fertilization in this vineyard in that year was 28 × 500 = 14,000 pounds per acre, but beyond the 32 pound increment of N the normal yield was drastically depressed. Growing conditions were apparently better in 1942 and the yields from all treatments were better. The first two increments define A = 22 as the normal yield curve, indicating a maximum possible yield in that year of 22 × 1,000

= 22,000 pounds (11 tons). Here, also, the normal yield was drastically depressed by the two higher increments of N. It is true that the normal curves are defined by only two points each; at least three are desirable; but as the pictures are substantially analogous for both crops, there is little reason to doubt that the normal curves have been correctly identified.

The fifth treatment in this experiment was 64 pounds of N, reinforced by 100 pounds of K. The corrective influence of K on the depressive effect of an excess of N is evident. In 1941 the yield of N plus K was 5.92 as against 5.73 units for N alone. This is a relatively small but still appreciable improvement. In the better 1942 season the normal yield from 64 pounds of N should have been 8.4 units (8,400 pounds). The actual yield was 7.02 units (7,026 pounds). The deficiency was thus 1,374 pounds. The addition of 100 pounds of K brought the 1942 yield to 7,542 pounds, thus reducing the deficiency to 858 pounds which represents an improvement of 37.5%. It is evidently proved that the higher increments of N threw this soil out of agrobiologic balance, and that the balance was at least partly restored by an addition of K. Full restoration of balance may require further experimentation on this soil, which, if successful, may well be profitable. The diagram intimates that 96 pounds of N should have raised the yield of the 1941 crop to $9.7 \times 500 = 4{,}850$ pounds, and in 1942 to $9.65 \times 1{,}000 = 9{,}650$ pounds.

Some astonishment might be evoked among New York viticulturists by the suggestion that with proper management their vines may have a potential yielding ability of up to 11 tons per acre; the potential may even be higher, depending on what value of N is found for insertion in the formula A *max.* = 318 N. But 11 or even 20 tons of grapes to the acre is no more fantastic than actual yields of 35 tons of tomatoes, or 225 bushels of corn, or 45 tons of sugar beets, or 1,300 bushels of potatoes, or 80 tons of sugar cane in one growing season. A serious fault of contemporary agriculture is its continuing failure to awake to the vast potentialities of its crop plants, and its neglect to capitalize on these potentialities by an intelligent application of quantitative agrobiologic science.

CONCLUSIONS

A survey of published field tests shows that in many cases persistent increase of the amount of fertilizer added to the soil results in depression of the normal yields of all kinds of crops, due to the creation of nutritional unbalance. Failure to preserve nutritional balance seems to be a major factor in repressing the fertility of the soil, and is one of the barriers to full exploitation of the known great inherent growth-energies of useful crops.

Measures for correcting or avoiding nutritional unbalance require first of all a means of recognizing it and measuring its degree. Such a means is found in the use of the standard yield diagram, which is based on the Mitscherlich-Baule theorem.

On the South Carolina farms represented in the examples here given soil nitrogen is evidently in excess when its total amount

exceeds 0.30 or 0.36 baule. Potash is out of balance when its amount exceeds 0.6 baule. In the Illinois soils considered, potash is not out of balance with corn and wheat when its average amount is about 2.0 baules. With soybeans, unbalance with potash begins at about 0.6 baule.

Proof is cited that nutritional or agrobiologic unbalance arising from an excess of one nutrient (N for example) may be corrected by an addition of a deficient nutrient. This corrective effect is, of course, just another verification of the agrobiologic law that quantitative plant growth depends on a harmonic balance of all its factors.

LITERATURE CITED

1. BRAY, R. H. The potash problem in Illinois. Better Crops, 28, No. 4:8-16; 42-44. 1944.
2. MITSCHERLICH, E. A. The second approximation of the effect law of growth factors. Zeitschrift f. Pflanzenernahrung usw.A 12:281. 1928. (Cf. Schriften d. Konigsberger Gehlerten Gesell, Naturwiss. Klasse, Heft 2. 1935.)
3. ROGERS, W. B. S. C. Agr. Exp. Sta. Bul. 283. 1932.
4. WELLINGTON, RICHARD, AND COLLISON, S. E. Use of nitrogen increases grape yields. Farm Res., 9, No. 4: 12. 1943.
5. WILLCOX, O. W. Yield-depression effect of fertilizers and its measurement by the universal yield diagram. Jour. Amer. Soc. Agron., 36:20-31. 1944.

MAINTENANCE LEVEL OF NITROGEN AND ORGANIC MATTER IN GRASSLAND AND CULTIVATED SOILS OVER PERIODS OF 54 AND 72 YEARS[1]

J. W. White, F. J. Holben, and A. C. Richer[2]

THE land now occupied by the Jordan Soil Fertility Plots of the Pennsylvania Agricultural Experiment Station was devoted to general farming from 1838 to 1868. In April, 1869, five tiers of 44 plots each were laid out and used for miscellaneous experiments until 1880. This pioneer experiment field, known as the Central Experimental Farm, was used for various tests in the nature of method of tillage, variety tests, and minor fertilizer experiments.

In 1881 a more comprehensive field plot experiment was established on the same area. This experiment, known until 1931 as the General Fertilizer Series, includes four tiers of 36 plots each. In 1931 the name was changed to the Jordan Soil Fertility Experiments in honor of its founder, W. H. Jordan. Since 1881 this experiment has been conducted as a four year grain rotation of corn, oats, wheat, and mixed hay in which the manurial treatments have been applied to corn and wheat.

The soil upon which the experiment is located is known as Hagerstown silt loam of limestone origin, typical of the most fertile Hagerstown soil found throughout the limestone valleys of Pennsylvania.

At the time the earlier plots were established, the land was in clover and timothy sod, seeded in 1867 and mowed the following year. The grass division strips which now separate each of the 144 plots of the four tiers and the six grass roadways between tiers have been in grass continuously since 1867. The grass was cut and raked once or twice each year since 1869. These permanent grassland areas have received no manurial treatments except occasional windblown materials which may have fallen upon the areas at the time the fertilizers were broadcast by hand on the plot areas. The grass division strips are 2 feet in width and the vegetation at the present time consists of Kentucky bluegrass, miscellaneous native grasses, and weeds. The roadways, 12 feet wide, support vegetation similar to that of the division strips with the exception of a scattered stand of white Dutch clover.

The cropping system followed on the Central Experimental Farm (1869–1880) was similar to that of the Jordan plots. Since the grassland areas described and the plot soils have been continuous since 1869, it becomes possible to determine the effect of the two systems of soil management for a maximum period of 72 years (1869–1940).

The relatively narrow division strips and roadways are not to be considered as entirely comparable with extensive grassland areas.

[1]Contribution from the Department of Agronomy, Pennsylvania State College, School of Agriculture, State College, Pa. Authorized for publication on August 15, 1944, as paper No. 1242 in the Journal Series of the Pennsylvania School of Agriculture. Received for publication August 18, 1944.

[2]Professor, Assistant Professor, and Associate Professor of Soil Technology, respectively.

The term grassland is used to distinguish between the cultivated plot soils and those in permanent sod.

The readers should keep in mind the fact that reduced erosion of the grassland soils is a contributing factor with respect to the accumulated nitrogen and organic matter in excess of that found in the plot soils.

EXPERIMENTAL PROCEDURE

At several periods of the Jordan Soil Fertility Experiments, the authors have sampled both the grassland areas and the respective plot soils ot representative treatments. The soil samples were taken to a depth of 7 inches by means of a standard soil auger. In sampling the grass division strips, the soil borings of the strips on each side of the plots were combined for comparison with the respective plot soils. On the grass roadways, two borings were taken opposite the ends of each of the 36 plots of the four tiers.

DATES OF SAMPLING

The roadways were first sampled in 1907 by the senior author under the direction of the late William Frear. The second sampling period was in 1938. The division strips and representative plot soils of tier I were sampled in 1922. In 1940 samples were secured from representative grass division strips and respective plot soils from each of the four tiers. These different sampling periods afforded an opportunity to determine the maintenance levels of nitrogen and organic matter at different periods of the experiment as influenced by the two systems of soil management.

Total nitrogen (Gunning method modified to include nitrogen of nitrates), organic carbon (White-Holben method),[3] and pH were determined on the fine soil that passed through a 20-mesh sieve. The carbon-nitrogen ratio of each soil is also included in the tables presented. The results are presented in terms of pounds per acre of nitrogen and organic matter (C $\times$ 1.724) based on an acre weight of 2,000,000 pounds of soil to a depth of 7 inches.

These calculations do not allow for possible differences in volume weight between the grassland and cultivated soils or for differences in organic matter and nitrogen content of the two soils below the depth of 7 inches.

PLOT TREATMENTS INCLUDED IN STUDY

The following Jordan plot treatments are included for comparison with the grassland soils: (1) Unfertilized; (2) PK, 48 pounds P_2O_5 and 100 pounds of K_2O; (3) PKN, PK and 48 and 72 pounds of nitrogen from nitrate of soda; (4) 6 tons manure on limed land; (5) 10 tons manure on limed and unlimed land.

The plot soils of tiers 1 and 3, included in these studies, have received no lime since 1881 with the exception of plot 22 (lime and 6 tons of manure treatment) which has been treated once each rotation with 2 tons of burnt lime. All plots of tiers 2 and 4 were limed in 1922 and 1923, respectively, with the exception of plot 25 (PK) of tier 4. Additional lime applications have been made in amounts indicated by frequent lime requirement determinations.

EXPERIMENTAL RESULTS

The average yields of air-dry matter per rotation (corn, oats, wheat, and mixed clover and timothy hay) of the Jordan plots and for the same plot areas of the original Central Experimental Farm are presented in Table 1.

[3]WHITE, J. W., and HOLBEN, F. J. Perfection of the chromic acid method for determining organic carbon. Jour. Ind. and Eng. Chem., 17: 83. 1925.

———, ———. Supplementary notes on the perfected chromic acid method for determining organic carbon. Jour. Assoc. Off. Agr. Chem., 17:334. 1934.

TABLE 1.—*Yields of the five Jordan plots used for comparison with the grassland soils, including also the average yields per rotation and treatments of the same plot soils of the former Central Experimental Farm (1869–1880).*

Central Experimental Farm plots, 1869–1880			Jordan plot, 1881–1940		Total yields of all crops in a rotation, lbs. on 4 acres						
					Average of each two rotations						
Plot No.	Plot treatment, 1869–1880	Yields in pounds per rotation (4 acres)	Plot No.	Plot treatment	1882–1889	1890–1897	1898–1905	1906–1913	1914–1921	1922–1930	Average 1882–1930
32	L + bonemeal	16,983	24	Untreated	14,562	11,907	8,855	8,432	8,215	8,266	10,037
33	L + bonemeal	17,606	25	PK	17,448	17,697	15,653	17,248	16,434	17,549	16,781
36	L + tankage	17,306	28	PKN	18,577	19,901	17,964	19,456	18,868	17,885	18,783
28	Untreated	14,757	20	10 tons manure	17,014	18,585	18,590	19,615	19,467	18,346	18,602
30	L + 6 tons manure	16,136	22	6 tons manure + L	17,306	18,974	17,787	19,417	19,342	18,274	18,516

The yields prior to 1881 are similar to those of the subsequent Jordan plots. With the one exception of the untreated plot soils, the yields have been maintained at a fairly constant level since 1869.

NITROGEN AND ORGANIC MATTER CONTENT, pH, AND CARBON-NITROGEN RATIOS OF THE GRASSLAND AND CULTIVATED PLOT SOILS OF TIERS 1, 2, 3, AND 4 AT THE END OF 72 YEARS (1869–1940)

The data secured from a study of the soils of the two systems of management at the end of 72 years are presented in Tables 2, 3, 4, 5, and 6. For convenience of comparison the percentages of nitrogen and organic matter (C × 1.724) were computed in terms of pounds per acre.

TABLE 2.—*Nitrogen, organic matter, pH, and carbon-nitrogen ratios of grassland (division strips) and plot soils of tier 1 after 72 years (1869–1940).*

Pounds per acre nitrogen and organic matter					
	Plot soil treatments since 1881				
	Untreated (14–24)	PK (15–25)	PKN (27)	Six tons manure + lime (22)	Ten tons manure (20)
Nitrogen, grassland soils	3,968	4,002	4,058	4,512	4,326
Nitrogen, plot soils	2,337	2,906	2,892	3,844	3,700
Excess over plot soils	1,631	1,096	1,166	668	626
Percentage excess over plot soils	69.8	37.7	40.3	17.4	16.9
Organic matter, grassland soils	92,600	90,700	90,400	100,600	93,600
Organic matter, plot soils	56,500	66,600	61,800	85,200	81,400
Excess over plot soils	36,100	24,100	28,600	15,400	12,200
Percentage excess over plot soils	63.9	36.2	46.3	18.1	15.0
pH, grassland soils	6.0	5.9	5.8	7.3	5.7
pH, plot soils	5.9	5.4	5.2	8.2	5.4
Carbon-nitrogen ratio, grassland soils	13.5	13.2	12.9	12.9	12.6
Carbon-nitrogen ratio, plot soils	14.0	13.3	12.4	12.9	12.8

A study of the several tables will show that on each of the four tiers of plots, the grassland soil had a nitrogen and organic matter content considerably above that of the cultivated plot soils. Carbon-nitrogen ratios are similar irrespective of the plot treatment and system of soil management followed during the 72-year period.

Based on the average figures of Table 6, the grassland soils have maintained an organic matter content in excess of the cultivated plot soils as follows: Percentage increase over untreated plot soils, 60.8; PK, 37.4; PKN, 41.5; 6 tons manure, 23.3; and 10 tons manure, 11.2. If the nitrogen content of the grassland soils is expressed as 100, the relative values of the five plot treatments will be as follows: 59, 71, 70, 84, and 89, respectively.

TABLE 3.—*Nitrogen, organic matter, pH, and carbon-nitrogen ratios of grassland (division strips) and plot soils of tier 2 after 72 years (1869–1940).*

Pounds per acre nitrogen and organic matter	Plot soil treatment since 1881				
	Un-treated (24)	PK (29)	PKN (28)	Six tons manure + lime (22)	Ten tons manure (20)
Nitrogen, grassland soils.......	3,548	3,460	3,842	4,038	3,550
Nitrogen, plot soils..........	2,122	2,598	2,582	3,258	3,386
Excess over plot soils	1,426	862	1,260	780	164
Percentage excess over plot soils	67.2	32.2	48.8	23.9	4.9
Organic matter, grassland soils	78,600	79,000	83,000	86,200	77,200
Organic matter, plot soils......	49,000	59,600	58,200	69,600	73,400
Excess over plot soils.........	29,600	19,400	24,800	16,600	3,800
Percentage excess over plot soils	60.4	32.5	42.6	23.8	5.2
pH, grassland soils..........	6.9	6.6	6.4	7.5	6.1
pH, plot soils......	7.4	6.8	6.8	8.5	7.0
Carbon-nitrogen ratio, grassland soils.........	12.9	13.2	12.5	12.4	12.6
Carbon-nitrogen ratio, plot soils	13.4	13.3	13.1	12.4	12.6

NITROGEN AND ORGANIC MATTER CONTENT AND CARBON-NITROGEN RATIO OF THE SOILS OF TIER 1 AT THE END OF 54 YEARS (1869–1922)

The results of the studies of the grassland and cultivated plot soils at the end of 54 years are included in Table 7. The nitrogen and

TABLE 4.—*Nitrogen, organic matter, pH, and carbon-nitrogen ratios of grassland (division strips) and plot soils of tier 3 after 72 years (1869–1940).*

Pounds per acre nitrogen and organic matter	Plot soil treatment since 1881				
	Un-treated (24)	PK (29)	PKN (28)	Six tons manure + lime (22)	Ten tons manure (20)
Nitrogen, grassland soils.......	3,288	3,102	3,362	3,700	3,332
Nitrogen, plot soils...........	1,802	2,034	2,286	2,998	3,022
Excess over plot soils	1,486	1,068	1,076	702	310
Percentage excess over plot soils	82.5	52.5	47.1	23.4	10.2
Organic matter, grassland soils	72,800	70,000	73,000	80,600	73,800
Organic matter, plot soils......	42,800	47,200	50,000	62,000	67,600
Excess over plot soils..........	30,000	22,800	23,000	18,600	6,200
Percentage excess over plot soils	70.1	48.3	46.0	30.0	9.2
pH, grassland soils...........	7.1	5.9	5.8	7.1	5.7
pH, plot soils................	5.7	5.4	5.9	8.4	5.6
Carbon-nitrogen ratio, grassland soils.....................	12.8	13.1	12.6	12.6	12.8
Carbon-nitrogen ratio, plot soils	13.8	13.5	12.7	12.0	13.0

and organic matter level of the grassland soils is again shown to be considerably above that of the cultivated plot soils.

TABLE 5.—*Nitrogen, organic matter, pH, and carbon-nitrogen ratios of grassland (division strips) and plot soils of tier 4 after 72 years (1869–1940).*

Pounds per acre nitrogen and organic matter	Plot soil treatments since 1881				
	Un-treated (24)	PK (25)	PKN (27)	Six tons manure + lime (22)	Ten tons manure (20)
Nitrogen, grassland soils	3,642	3,800	3,980	3,806	3,906
Nitrogen, plot soils	2,328	2,724	2,970	3,380	3,406
Excess over plot soils	1,314	1,076	1,010	420	500
Percentage excess over plot soils	56.5	39.5	34.0	12.4	14.7
Organic matter, grassland soils	78,200	82,800	85,200	80,000	80,000
Organic matter, plot soils	52,000	61,400	64,400	69,000	69,600
Excess over plot soils	26,200	21,400	20,800	11,000	10,400
Percentage excess over plot soils	50.4	34.8	32.3	15.9	14.9
pH, grassland soils	7.5	6.3	6.3	7.6	6.8
pH, plot soils	7.1	5.5	6.5	8.3	7.1
Carbon-nitrogen ratio, grassland soils	12.5	12.6	12.4	12.2	11.9
Carbon-nitrogen ratio, plot soils	13.0	13.1	12.3	11.8	11.9

CHANGES IN MAINTENANCE LEVEL OF NITROGEN AND ORGANIC MATTER DURING AN 18-YEAR PERIOD BETWEEN 1922 AND 1940, TIER 1

The relative changes in nitrogen and organic matter content of the grassland and cultivated plot soils during the last 18 years of

TABLE 6.—*Summary of the four tiers showing the average maintenance level of the plot soils, compared with the grassland areas, as influenced by commercial fertilizer and manure, 72 years (1869–1940).*

Pounds per acre of nitrogen and organic matter	Plot soil treatments since 1881				
	Un-treated	PK	PKN	Six tons manure + lime	Ten tons manure
Nitrogen, grassland soils	3,612	3,591	3,810	4,014	3,779
Nitrogen, plot soils	2,147	2,565	2,682	3,370	3,379
Excess over plot soils	1,465	1,026	1,128	644	400
Percentage excess over plot soils	68.2	40.0	42.1	19.1	11.9
Organic matter, grassland soils	80,550	80,625	82,900	85,150	81,150
Organic matter, plot soils	50,075	58,700	58,600	69,050	73,000
Excess over plot soils	30,475	21,925	24,300	16,100	8,150
Percentage excess over plot soils	60.8	37.4	41.5	23.3	11.2
Carbon-nitrogen ratio, grassland soil	12.9	13.0	12.6	12.5	12.5
Carbon-nitrogen ratio, plot soils	13.5	13.3	12.7	12.2	12.6

TABLE 7.—*Nitrogen, organic matter, and carbon-nitrogen ratios of grassland (division strips) and plot soils of tier 1 after 54 years (1869–1922).*

Pounds per acre nitrogen and organic matter					
	Plot treatments since 1881				
	Untreated (14)	PK (15)	PKN (27)	Six tons manure (16)	Six tons manure + lime (22)
Nitrogen, grassland soils	3,630	3,740	3,830	3,980	4,290
Nitrogen, plot soils	2,470	2,964	2,880	3,330	3,690
Excess over plot soils	1,160	776	950	650	600
Percentage excess over plot soils	46.9	26.2	33.0	19.5	16.3
Organic matter, grassland soils	75,600	78,500	79,400	85,900	90,700
Organic matter, plot soils	55,500	62,000	59,600	72,600	78,500
Excess over plot soils	20,100	16,500	19,800	13,300	12,200
Percentage excess over plot soils	36.2	26.6	33.2	18.3	15.6
Carbon-nitrogen ratio, grassland soils	12.1	12.2	12.0	12.6	12.3
Carbon-nitrogen ratio, plot soils	13.0	12.1	12.0	12.6	12.3

the sampling periods (1922–1940) are shown in Table 8. In each case the grassland soils adjacent to the plot areas showed a substantial gain of nitrogen and organic matter equivalent to an average of 276 pounds of nitrogen and 11,550 pounds of organic matter, or an average annual gain of 15.3 and 642 pounds, respectively. With the exception of the untreated area, the plot soils showed relatively little change in nitrogen and organic matter content during the 18-year period. The small differences, especially with respect to the PK and PKN treatments, are within the limits of experimental error. It is of importance here to point out the fact that the grassland soils at the end of 72 years (1869–1940) in continuous grass still show a gain or continued accumulation of nitrogen and organic matter.

If we assume that the average annual yields of grass removed from the division strips has been 1,000 pounds per acre (a conservative estimate), then the nitrogen removed annually in crops of grass would be approximately 25 pounds and the soil gain has averaged 15.3 pounds or an annual nitrogen fixation of 40.3 pounds per acre, excluding the small annual amount added in rainwater and snow.[4]

INCREASE IN NITROGEN AND ORGANIC MATTER CONTENT OF GRASS ROADWAY SOILS DURING A PERIOD OF 32 YEARS (1907–1938)

Table 9 includes the data secured from a study of the grass roadways in 1907 and 1938. A study of the results secured between these two sampling periods of 32 years will show that, as in grass strip soils, there occurred a pronounced gain in nitrogen and organic matter during the 32-year period. The roadway soils show an average

[4]At the end of a 4-year period of grass in a rim experiment, the average annual fixation of nitrogen has been 42.8 pounds per acre in the absence of clover and with no Azotobacter present in the soil.

TABLE 8.—*Changes in maintenance level of nitrogen and organic matter of the grassland (division strips) and plot soils during an 18-year period (1922–1940), tier 1.*

	Pounds per acre of nitrogen and organic matter									
		Plot treatments since 1881								
	Grass-land soil	Untreated (14)		PK (15)		PKN (27)		Six tons manure + lime	General average	
		Plot soil	Grass-land soil	Plot soil	Grass-land soil	Plot soil	Grass-land soil	Plot soil	Grass-land soil	Plot soil
Nitrogen, 1940	4,008	2,262	4,012	2,936	4,058	2,892	4,512	3,844	4,148	2,984
Nitrogen, 1922	3,630	2,470	3,740	2,964	3,830	2,880	4,290	3,690	3,872	3,001
Gain (+) or loss (–)	+378	–208	+272	–28	+228	+12	+222	+154	+276	–17
Annual gain (+) or loss (–)	+21.0	–11.6	+15.1	–1.5	+12.7	+0.7	+12.3	+8.6	+15.3	–0.9
Organic matter, 1940	91,400	53,400	88,000	63,800	90,400	61,800	100,600	85,200	92,600	66,050
Organic matter, 1922	75,600	55,500	78,500	62,000	79,400	59,600	90,700	78,500	81,050	63,900
Gain (+) or loss (–)	+15,800	–2,100	+9,500	+1,800	+11,100	+2,200	+9,900	+6,700	+11,550	+2,150
Annual gain (+) or loss (–)	+878	–117	+528	+100	+617	+122	+550	+372	+642	+120

annual gain of 32.3 pounds of nitrogen compared with 15.3 pounds (Table 8) for the grass strip soils. This may be attributed to two causes: (1) The grass strips are more severely drained due to dead furrows produced by plowing. This would have the effect of lowering the water retentive power of the soil as compared to the more flat roadway area. (2) The growth of white Dutch clover in the roadways has no doubt increased the nitrogen fixed. The total nitrogen and organic matter content of the grass strips and roadways are quite similar. Reference to Table 6 will show that the grass strip soils in 1940 contained, on an average of the four tiers, 3,748 pounds of nitrogen and 82,301 pounds of organic matter compared with 3,930 pounds of nitrogen and 86,700 pounds of organic matter found in 1938 in the roadway soils. It is of interest to note the relatively high pH of these roadway soils which have received no lime since 1867 equivalent to an unlimed period of 72 years(1867–1938). The grassland soils, including both the grass division strips and roadways, even after 72 years in continuous grass, have not reached an equilibrium with respect to nitrogen and organic matter. Both grass areas are still producing a normal growth estimated at from 1,000 to 2,000 pounds per acre.

Further evidence of the more rapid accumulation of nitrogen and organic matter in continuous grassland soils compared with those in a long-time cultivated system, involving a 4-year grain rotation, is presented in Table 10. The plot soils data are based on the composition of the soil in 1931 compared with the 1938 roadway samples. These two sampling periods are comparable, however, since, as already stated, the plot soils show only slight variation in composition from year to year. Thus, in 1915, the plot soils of tier 4 contained on an average 2,698 pounds of nitrogen compared with 2,662 found in 1931. The organic matter was 62,400 and 61,200 pounds, respectively. The small differences are within the limits of experimental error (0.0018% nitrogen and 0.035% organic carbon).

GENERAL SUMMARY OF THE MAINTENANCE LEVEL OF NITROGEN AND ORGANIC MATTER IN THE GRASSLAND AND CULTIVATED PLOT SOILS

At the end of 72 years the soils of the grass strips, based on an average of the four tiers, have maintained a nitrogen level 33.6% above the five cultivated plot soils and at the end of 54 years of tier 1 a nitrogen level 26.9% above the cultivated soils of that tier. The soils of the two grass roadways on each side of tier 1 at the end of 70 years (1869–1938) show an average nitrogen level 48.6% above the general average of the 36 cultivated plot soils and on tier 4 the two grass roadway soils show a nitrogen level 48.8% above the average of the 36 plot soils. Each tier of 36 plots includes 24 different treatments. The plot soil which received 20 tons manure per rotation (tier 4) shows the highest nitrogen content (3,292 pounds per acre in 1931). The roadway soil had a nitrogen content 20.3% above the manure treated soil. The five untreated plots distributed throughout each tier (Nos. 1, 8, 14, 24, 36) show an average nitrogen content

TABLE 9.—*Increases in nitrogen and organic matter content of grassland (roadways) soils during a 32-year period (1907–1938).*

Pounds per acre of nitrogen and organic matter					
	Roadways at two sides of tier 1	Roadways west side tier 3	Roadways between tiers 3 and 4	Roadways east side of tier 4	General average
Nitrogen, 1938......	3,980	3,816	4,238	3,684	3,930
Nitrogen, 1907......	3,169	2,504	3,012	2,904	2,897
Increase............	811	1,312	2,126	780	1,033
Average annual gain	25.3	41.0	38.3	24.4	32.3
Organic matter, 1938	96,500	79,600	88,600	82,200	86,700
Organic matter, 1907	73,600	63,400	68,800	71,900	69,400
Increase............	22,900	16,200	19,800	10,300	17,300
Average annual gain	716	507	619	322	541
pH, 1938...........	6.5	6.7	6.3	6.8	——

of 2,292 pounds per acre (tier 4) compared with 3,961 pounds found in the grass roadway soil equivalent to a nitrogen level 72.9% above the untreated soil. A similar comparison of the soils of tier 1 shows that the five untreated plot soils contain, on an average, 2,284 pounds of nitrogen per acre compared with 3,980 pounds for the average of the two grass roadways equivalent to a nitrogen level 74.2% above the untreated cultivated soil as measured at the end of 70 years (1869–1938).

TABLE 10.—*General summary of the maintenance level of nitrogen and organic matter in grassland and cultivated plot soils, grass division strips and roadways vs. cultivated plot soils.*

Pounds per acre of nitrogen and organic matter					
	Tiers 1-2-3-4 (average) grass strips vs. 5 plot soils (average) 1869–1940, 72 yrs.	Tier 1 grass strips vs. 5 plot soils (average) 1868–1922, 54 yrs.	Tier 1 grass roadways vs. 36 plot soils (average) 1869–1938, 70 yrs.*	Tier 4 grass roadways vs. 36 plot soils (average) 1869–1938, 70 yrs.*	General average, 67 yrs.
Nitrogen, grassland soils...	3,748	3,894	3,980	3,961	3,896
Nitrogen, cultivated plot soils..................	2,805	3,067	2,678	2,662	2,803
Excess over plot soils.....	943	827	1,302	1,299	1,093
Percentage excess.........	33.6	26.9	48.6	48.8	39.0
Organic matter, grassland soils..................	82,300	82,000	96,500	85,400	86,550
Organic matter, cultivated plot soils..............	62,000	65,600	62,200	61,200	62,800
Excess over plot soils......	20,300	16,400	34,200	24,200	23,750
Percentage increase.......	32.8	25.0	54.9	39.5	37.8

*Based on the 1931 sampling period of plot soils (see text).

SUMMARY AND CONCLUSIONS

1. Studies of 20 plot soils (five treatments on each of the four tiers) at the end of 72 years (1869–1940) of continuous cultivation in a 4-year grain rotation and the adjacent grassland areas in permanent grass for the same period have shown that in every one of the 20 comparisons the grassland soils have maintained a nitrogen and organic matter level considerably above that of the plot soils.

2. The unfertilized grassland soils at the end of 72 years show a nitrogen level 68.2% above the unfertilized plot soil, 40.0% higher than the PK treatment, 42.1% above the NPK treatment, 19.1% above the soil treated with 6 tons of manure and lime, and 11.9% above the 10 tons manure treatment (1881–1940 biennial plot treatments).

3. The carbon-nitrogen ratios of the cultivated plot soils and those in permanent grass are quite similar. The pH of the unlimed plot soils (tiers 1 and 3) and the grassland soils were found to be approximately the same.

4. At the end of 54 years (1869–1922, tier 1) the grassland soils showed a nitrogen level 46.9% above the untreated plot soil, 26.2% above the PK treatment, 33.0% above the NPK treated soil, 19.5% above the 6 tons manure and lime treatment, and 16.3% above the plot soil which has received 10 tons of manure (1881–1940).

5. At the end of 70 years (1869–1938) the grass roadways on each side of tier 1 have maintained a nitrogen level 48.6% above the average of the 36 plot soils which includes 24 different treatments. A similar comparison on tier 4 shows that the grassland soils have a nitrogen content 48.8% above the 36 cultivated plot soils.

6. The grass roadway soils of tier 4 have maintained a nitrogen level 20.3% above the plot soil which has received biennially 10 tons of manure and a level 72.9% above the average of the five unfertilized plot soils.

7. The Jordan plot soils which have received biennial treatments of 48 pounds of phosphoric acid (P_2O_5) and 100 pounds of potash (K_2O) per acre since 1881 have maintained approximately the same nitrogen level as the plot soils which have been treated with heavy dressings of nitrate of soda, supplying 48 and 72 pounds of nitrogen per acre. Thus, on the two unlimed tiers (1 and 3), the NPK treatment has maintained a nitrogen level only 4.8% above the PK-treated plots compared with 4.3% for the two limed tiers (2 and 4).

This significant fact, together with the high nitrogen content of the untreated grassland soils, serves to emphasize the importance of the nitrogen fixation in the scheme of soil fertility maintenance.

The only source of energy materials supplied the grassland soils since 1867 has been the sloughed off roots of grasses and weeds and the crop residues (roots and stubble) in the case of the plot soils which have received no manure.

CYTOLOGICAL AND GENETICAL STUDIES OF THE INTERSPECIFIC CROSS OF THE CULTIVATED FOXTAIL MILLET, *SETARIA ITALICA* (L.) BEAUV., AND THE GREEN FOXTAIL MILLET, *S. VIRIDIS* L.[1]

H. W. Li, C. H. Li, and W. K. Pao[2]

THE cultivated foxtail millet, *Setaria italica*, is extensively grown in the Far East, notably in China and India. Its wild relative, the green foxtail, *S. viridis*, which is a native of the old world according to Piper (6),[3] differs from the cultivated forms in many respects, such as growth habit, plant height, seed shattering, etc. The distribution of the green foxtails in China, from Manchuria to Southwest China, is in close association with the cultivated form. That is to say, wherever the cultivated form is seen, inevitably the wild form also can be found. Both forms furthermore, have nine pairs of chromosomes. In short, they are, in many respects highly related. It is, therefore, of much interest to determine their relationships cytologically and genetically.

MATERIAL AND METHODS

A number of attempts have been made to hybridize these two species artificially but without success. In 1938, hybridization again was tried on a large scale and a number of supposedly hybrid seeds were obtained. However, only one plant among all those grown proved to be a hybrid. The *S. italica* was the female parent of this cross. The hybrid plant was grown carefully in an earthen pot. The heads were bagged to avoid cross pollination. Nevertheless, some seeds from unbagged flowers were grown and were sown in order to increase the size of the F_2 population.

Some 4,000 seeds were sown in wooden flats in the greenhouse, but only half of these germinated. When the seedlings reached a height of about 1 inch, they were transplanted to the field, being set 2 inches apart. The final population of the F_2 generation was 1,250 plants. Careful records were undertaken on each plant from time to time, both in the field and in the laboratory.

In the F_3 generation, 100 lines were grown in order to verify the F_2 ratios. The final population of each line was 45 to 185 plants, but a majority had more than 100 plants. About 78 lines were carefully studied, while the other 22 lines were discarded because of lack of time for detailed study.

For cytological study of the pollen mother cells, the heads were fixed in acetic-alcohol (1 part glacial acetic acid and 3 parts absolute alcohol). After about 24 hours, they were transferred from the fixative to 90% alcohol where they remained for 1 or 2 days and then they were preserved in 70% alcohol. The aceto-carmine smear method was used exclusively.

Iodine-potassium iodide was used as a stain in pollen analysis.

---

[1]Journal series No. 9 of the Rice and Wheat Improvement Institute of the Szechuan Provincial Agricultural Improvement Institute, China. Received for publication August 18, 1944.

[2]Director of the Rice and Wheat Improvement Institute and Professor of West China Union University, Assistant Professor of West China Union University, and Technician of the Szechuan Experimental Station of the Ministry of Agriculture and Forestry, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 54.

CYTOLOGICAL STUDY OF THE HYBRID

Li, *et al.* (3) reported 9 chromosomes as the haploid number of both *S. italica* and *S. viridis* found in Honan Province, China. Krishnaswami, *et al.* (2) reported the same number in *S. italica*. The haploid number of both parents, *S. italica* and *S. viridis*, in the present cross was also determined to be 9. As expected, the hybrid had 18 chromosomes and formed 9 chromosome complements at meiotic diakinesis. The pairing between all the 9 pairs seemed to be perfect (Fig. 1), and all the stages subsequent to diakinesis up to the quartet appeared to be normal. However, from pollen analysis, about 70% of the pollen grains were rather deformed and devoid of starch. Sterility in the hybrid seemed to be high as an estimated 50% of the spikelets were empty. The time and manner of the degeneration of the pollen grains still remains to be determined. The sterility of the F_2 generation varied from very high to as low as that of the parents. It seems, therefore, that sterility is inherited. Owing to the lack of sufficient time and the difficulties in making exact determination of the percentage of empty spikelets, the sterility factor has not been studied in detail.

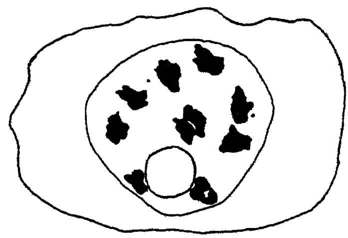

FIG. 1.—Diakinesis in the F_1 hybrid between *Setaria italica* and *S. viridis* showing complete pairing of chromosomes. × 1300.

GENETICAL STUDIES OF THE HYBRID

The female *italica* parental strain is resistant to kernel smut. The male *viridis* parent is indigenous to Chengtu, found everywhere along the roadsides or in the field as weeds (Fig. 2). Altogether eight qualitative characters were studied, as follows:

Species	Seedcoat color	Pericarp color	Endosperm color	Seed shattering
S. italica	Korra-buff	White	White	Nonshattering
S. viridis	Black	Black	Yellow	Shattering
F_1	Black	White	Yellow	Shattering
	Growth habit	Plant color	Bristle color	Anther color
S. italica	Erect	Green	Green	White
S. viridis	Prostrate	Purple	Purple	Brown
F_1	Prostrate	Purple	Purple	Brown

In the eight characters studied, the F_1 plant resembles the *viridis* type except for pericarp color. That is to say, the wild relative of the cultivated millet carries most of the dominant factors. However, it must be borne in mind that in the selection of the *italica* parent, the type that has supposedly many recessive factors is chosen in prefer-

ence to other types. In addition to these qualitative characters studied, there are other quantitative characters under observation as well, such as the height of plant, number of tillers per plant, time of heading, and the length of the head (Figs. 3 and 4). All these quantitative characters studied are intermediate for F_1. Unimodal F_2 distributions are obtained when the measurements are plotted graphically. Particular reference should be made here to the fact that several of the characters such as the width of the leaf, number of tillers per plant, and the height of the plant, show transgressive segregation in the second generation. All these show the possibility that several factors are involved in the manifestation of these quantitative characters. Unfortunately, no further studies have been undertaken.

FIG. 2.—Heads of the parents and their hybrid. A, *Setaria italica*; B, *S. italica* × *S. viridis*; C, *S. viridis*. Note the degree of seed shattering.

SEEDCOAT COLOR

When the korra-buff colored seedcoat of *italica* parent is crossed with the blackcoated *viridis*, F_1 is black and F_2 segregates for black, tawny buff, and korra buff, as shown in Table 1.

TABLE 1.—*Segregation for seedcoat color in the F_2 generation.*

Seedcoat color	Observed	Calculated	Ratio
Black	545	527.34	27
Tawny buff	178	175.78	9
Korra buff	527	546.88	28
Total	1,250	1,250.00	

$X^2 = 1.342$ P = .513

The F_2 segregation is explained on the supposition that it involves the interaction of three factors, R, Vi, and B. R and Vi are the complementary factors for the production of tawny buff, and B is a supplementary factor for the production of black pigment in the presence of R and Vi. The theoretical ratio for black, tawny buff, and korra buff is, therefore, 27:9:28. The fit between the observed and the calculated, as indicated by the P value (.513), is quite good. Moreover, this is further proved to be the case by the F_3 segregations of

the F_2 black seedcoat plants. Since the black pigment of the seedcoat, as supposed, is due to the co-existence of all these three factors, then four types of segregation, namely, 27 black seedcoat to 37 others, 9 to 7, 3 to 1, and pure breed of black in 8:12:6:1 ratio, must be expected in F_3. This expectation is realized by the F_3 data as presented in Table 2.

Rangaswami Ayyangar (7) and Li, *et al.* (4) reported that there are three independent factors, K, R, and B, in interaction for the manifestation of the different seedcoat colors as follows:

K R B	Black	k R B	Sepia
K R b	Tawny buff	k R b	Red
K r B K r b	Korra buff	k r B k r b	Tawny red

FIG. 3.—Some variants of the F_2 progeny of the cross *S. italica* × *S. viridis*, showing variation in number of tillers and height of plants.

TABLE 2.—*Segregation for seedcoat color in the F_3 generation of progenies of blackcoated F_2 plants.*

Segregated to	Observed	Calculated	Ratio
27 black : 37 others	16	19.84	8
9 black : 7 others	35	29.76	12
3 black : 1 other	14	14.88	6
All black : No others	2	2.48	1
Total	67	66.96	

$X^2 = 1.810$ $P = .618$

In the present cross, the factor K must be present in the homozygous condition in both parents used lest another set of seedcoat colors should appear in addition to the present set. Therefore, the factor Vi, hereby introduced, has a supplementary effect for the production of black pigment only in the presence of the factor K.

ENDOSPERM COLOR

The endosperm color of *italica* is white. It is yellow for *viridis* and for their F_1 hybrid. In the F_2 generation it segregates into about 3

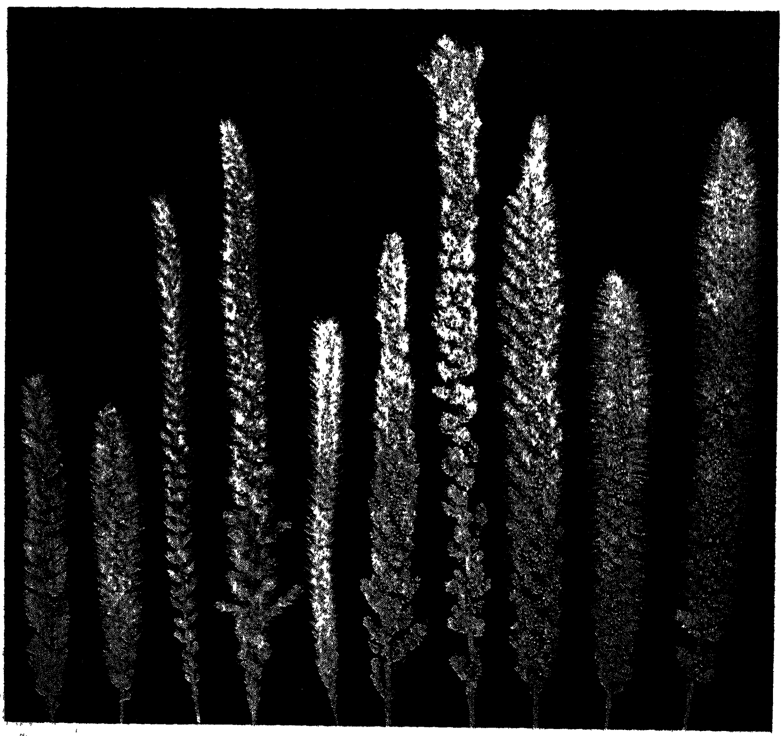

FIG. 4.—Some different head types of the F_2 progeny.

yellow to 1 white, as shown in Table 3. This is a simple Mendelian segregation with yellow dominant over white. The F_3 data (Table 4) have proved it to be the case. The factor pair is, therefore, assigned Yy.

TABLE 3.—*Segregation for endosperm color in the F_2 generation.*

Endosperm color	Observed	Calculated	Ratio	Difference
Yellow	939	937.5	3	
White	311	312.5	1	1.5 ± 15.31
Total	1,250	1,250.0		

TABLE 4.—*Segregation for endosperm color in the F_3 generation.*

Segregated to	Observed	Calculated	Ratio
All yellow	23	17.5	1
3 yellow : 1 white	35	35.0	2
All white	12	17.5	1
Total	70	70.0	

$X^2 = 3.458$ $P = .183$

In the study of the endosperm of the foxtail millet, Li, *et al.* (4) reported that white was found to be dominant over yellow. These two yellows might be different entirely or an inhibitor may be involved when white is dominant over yellow.

SEED SHATTERING

The foxtail millet has its seeds intact when mature. On the other hand, the seeds drop off from the wild foxtail as they mature. The ripened seeds drop off rather badly from the hybrid but not to the extent as from the *viridis* parent. In the classification for the F_2 and F_3 generations, an arbitrary standard was adopted. Types like the hybrid would be classified under shattering. From Table 5, the difference of the observed frequency from the calculated is less than twice its standard error. Thus, it can be concluded that the inheritance of seed shattering is due to the interaction of two complementary factors, S and H.

TABLE 5.—*Segregation for seed shattering in the F_2 generation.*

Mature seeds	Observed	Calculated	Ratio	Difference
Shattered	732	703	9	
Nonshattered	518	547	7	29 ± 17.54
Total	1,250	1,250		

The seed-shattering character was not taken into consideration in selecting F_2 plants used for raising F_3 generation. According to the stated factorial hypothesis, the F_3 lines would be sorted into

four groups, e.g., segregating for 9 shattering to 7 nonshattering, 3 shattering to 1 nonshattering, and pure shattering, pure non-shattering, in the relative proportions 4, 4, 1, 7, respectively. These four groups are realized in the F_3 generation (Table 6), although the frequencies are rather significantly different from the calculated ones. It seems probable, however, that two factors are definitely involved in such a mode of segregation.

TABLE 6.—*Segregation for seed shattering in the F_3 generation.*

Segregated to	Observed	Calculated	Ratio
9 shattering : 7 non	22	17.00	4
3 shattering : 1 non	13	17.00	4
All shattering	9	4.25	1
All nonshattering	24	29.75	7
Total	68	68.00	

$X^2 = 8.832$ $P = .035$

SEEDLING TYPE

The *italica* parent has practically no tillers and is erect in habit of growth, whereas, *viridis* tillers profusely and is prostrate in the seedling stage. The F_1 plant has many tillers and the growth habit, although somewhat intermediate, simulates closely the prostrate type. All degrees of profuseness of tillering and erectness of growth habit were manifested in the F_2 generation. Plants with few or no tillers resembled the erect type. When tillers are formed in great abundance, the classification for growth type becomes quite difficult. Therefore, the classification of the F_2 plants was by no means exact, although the plants were carefully observed. About 695 plants out of 1,250 F_2 population were classified as prostrate. If two complementary factors are hypothecated to explain the result, the fit is quite good. Prostrate F_2 plants only were used as seed stocks for the F_3, and of 78 lines tested, 52 segregated and 26 bred true for the prostrate type. This is a case of simple Mendelian segregation. It can be concluded, therefore, that one factor pair Ps ps is involved in the inheritance of seedling type. The dominance of the prostrate gene Ps is not complete, and the expression of growth habit is influenced to some extent by the profuseness of tillering.

PLANT COLOR

The seed parent *S. italica* is green in all the vegetative parts both in the seedling and the mature stages. On the other hand, the male parent *S. viridis* is intensely purple, especially in the stem nodes and leaf-sheath junctions. The F_1 resembles the *viridis* parent. In addition to the parental color types, i.e., green and intense purple, a light purple type segregates out in the F_2 generation. The observed and calculated frequencies are shown in the Table 7.

The calculation is based upon the supposition of the interaction of two factors, P, a main factor for the production of purple pigment,

and In, the intensifier of the factor P. The agreement between the observed and the calculated frequencies is very good.

TABLE 7.—*Segregation for plant color in the F_2 generation.*

Plant color	Observed	Calculated	Ratio
Intense purple	700	703.13	9
Light purple	230	234.37	3
Green	320	312.50	4
Total	1,250	1,250.00	

$X^2 = 0.276$ $P = 0.872$

Only intensely purple F_2 plants were used in raising the F_3 generation. The F_3 data as presented in the Table 8 have proved that the above-stated two factor hypothesis is valid.

TABLE 8.—*Segregation for the plant color in the F_3 generation of progenies of purple F_2 plants.*

Segregated to	Observed	Calculated	Ratio
9 purple : 7 others	35	31.11	4
3 purple : 1 light purple	14	15.56	2
3 purple : 1 green	14	15.56	2
All purple	7	7.78	1
Total	70	70.01	

$X^2 = 0.883$ $P = 0.830$

Rangaswami Ayyangar, *et al.* (8) studied the inheritance of the purple pigmentation of the foxtail millet and postulated that the different color tones are due to the result of the interaction of four factors, P, I, V, and H. The effects of the factors P and I correspond with those shown for P and In above, whereas V and H were assumed to affect the expression of purple coloration in the vegetative parts and in the earhead, respectively. Six color types were used in their classification. It is well known that the color intensity of the vegetative parts is, to some extent, affected by changes in environmental conditions, such as temperature, drought, and fertility. In the present case, however, the light-purple coloration can be easily discerned by its faintness of purple pigmentation whatever the environmental conditions may be. Within the purple type, it must be confessed that the color intensity does vary to some extent. Since such variation, perhaps of less extent, also exists within the different tillers of a single plant, it becomes quite difficult to classify these minor variations into definite categories as was done by Rangaswami Ayyangar, *et al.* (8). For this reason, no attempt has been devoted in the verification of the presence of the factors V and H.

BRISTLE COLOR

The bristles of *italica* are green, while those of *viridis* and the hybrid are purple. The segregation for the bristle color in the F_2

generation is somewhat complex when the three classes, purple, light purple, and green, were adopted in classification. Unlike the plant color, no sharp demarcation exists between the purple and light-purple types of bristle. For the sake of simplicity, the two types, purple and light purple are combined into one. The observed ratio thus can be explained by assuming the presence of triplicate factors Pr_1, Pr_2, and Pr_3, with Pr_1 and Pr_2 linked together. In the presence of any of the triplicate factors, the bristle color will be purple. The crossing-over value as calculated by means of Fisher's maximum likelihood method is 20.81%. The calculated frequency fits well to the observed (Table 9).

TABLE 9.—*Segregation for the bristle color in the F_2 generation.*

Bristle color	Observed	Calculated	Ratio	Difference
Purple	1,201	1,200.78	15.37	
Green	49	49.22	0.63	0.78 ± 6.88
Total	1,250	1,250.00		

All F_2 plants used as seed stocks for the F_3 generation had purple bristles. The F_3 data are presented in Table 10.

TABLE 10.—*Segregation for the bristle color in the F_3 generation of progenies of purple bristled F_2 plants.*

Segregated to Purple : Green	Observed		Calculated		
	Number of lines	Average % of green	Number of lines	% of green	Ratio
3 : 1 (independent)	13	27.63	8.71	25.00	1.9134
15 : 1 (independent)	10	8.12	6.00	6.25	1.3184
15 : 1 (repulsion)	3	1.43	0.40	1.08	0.0866
63 : 1 (repulsion)	0	——	0.79	0.27	0.1732
15 : 1 (coupling)	17	14.81	5.71	15.63	1.2542
63 : 1 (coupling)	6	3.64	11.42	3.91	2.5084
All : 0	21	0.00	36.97	0.00	8.1187
Total	70		70.00		15.3729

The number of lines is too small to fit such a complex ratio for the segregation in F_3. Moreover, the number of plants of each line was not large enough as to distinguish the six segregating types with a high degree of accuracy. Therefore, it seems to be unnecessary to use the X^2 test. But, from the data, it is clear that the observed frequency has a general tendency to coincide with the expected one.

ANTHER COLOR

The *italica* parent has white anthers and the *viridis* brownish yellow anthers. The F_1 is brownish yellow. In the F_2 generation, 867 of 1,250 plants had brownish yellow anthers. This deviates significantly from a 3:1 ratio (diff. 70.5±15.31), thus suggesting some factor or factors that disturb the normal ratio. From the fact that

many F_2 seeds do not germinate, together with the high sterility in the pollen grain, a lethal factor linked with anther color with a crossing-over value of 25.67% is hypothecated. This seems to explain the situation, but when linkage relations with other characters are studied, this hypothesis must be abandoned. A gametophyte factor linked with anther color might be suggested. Such a hypothetical "gamete" gene, Ga, in maize was proposed by Mangelsdorf and Jones (5) and by Emerson (1). The action of this gene, however, is not yet fully determined. In the case of maize, the ga pollen in competing with that of Ga can function on the Ga pistil from zero to about 4% in the production of kernels, according to Emerson (1). The percentage of the functioning ga pollen is thus negligible. For this reason, ga pollen is assumed to be wholly functionless in competition with the Ga pollen in the present case. This assumption will be proved in the later calculations.

The gametophyte factor Ga is linked with the brown anther color factor Br in the repulsion phase, since the white anther plants are in excess in the F_2 segregation. Let p and q be the ratio of the non-crossing-over and crossing-over gametes, respectively. Then the expected frequency of the brown- and white-anthered plants in the F_2 generation can be formulated as $p^2+3pq+2q^2$ and p^2+pq, respectively. In equating these formulae with their respective observed frequency and solving the equations for p and q, the crossing-over value between the genes Ga and br is calculated to be 38.72%.

Seed from plants with only brown anther color were used for growing the F_3 generation. According to the stated hypothesis, three kinds of segregation may be expected for the segregating lines in the F_3 generation. These are segregation with recessive phenotypes in deficiency (about 19%), normal (about 25%), and in excess (about 31%). Actually, the percentage of the recessive varies widely among the segregating lines, 39.71% for the highest one and 15.29%, the lowest. Since the population of individual lines is too small to discern the above three kinds of segregation with reasonable accuracy, the plants were classified under only two categories, segregating and nonsegregating. The disparity between the observed and calculated frequency is insignificant, with a difference less than twice its standard error (Table 11). The detailed calculation pertaining to this will be stated later.

TABLE 11.—*Segregation for the anther color in the F_3 generation of progenies of plants with brown anthers.*

Type of line	Observed	Calculated	Ratio	Difference
Segregating...........	67	62.48	572.1854	
Non-segregating.......	3	7.52	68.8171	4.52 ± 2.59
Total................	70	70.04	641.0025	

PERICARP COLOR

The F_1 plants from the cross between *italica* (white pericarp) and *viridis* (black pericarp) had a white pericarp. In the F_2 generation,

1,020 of 1,250 plants had a white pericarp and the remaining 230 plants were black. This result can be explained satisfactorily by the interaction of two factors, one for the manifestation of black pigment and another for a dominant inhibitor of the color gene. However, when this character is studied in combination with the anther color, it reveals that these two characters are in some way linked. Since the anther color is linked with the gametophyte factor, Ga, so by inference Ga is also linked with the pericarp color. It seems, therefore, that the F_2 ratio for pericarp color is not due to the interaction of two factors as stated, but due to the disturbance of a simple Mendelian segregation by the same gametophyte factor Ga as for the anther color. By means of the same method as used above, the crossing-over value between the gene Ga and the factor W for the white pericarp color is calculated to be 36.80%.

All F_2 plants used for testing in the F_3 generation had a white pericarp. The observed proportion of segregating and nonsegregating lines of the F_3 fits satisfactorily with the calculated one based on the hypothesis (Table 12).

TABLE 12.—*Segregation for the pericarp color in the F_3 generation.*

Type of line	Observed	Calculated	Ratio	Difference
Segregating...........	58	60.43	553.3408	
Nonsegregating.......	12	9.57	87.6617	2.43 ± 2.87
Total...............	70	70.00		

LINKAGE RELATION BETWEEN ANTHER AND PERICARP COLOR

The observed frequency for the anther and pericarp color combined shows that their factors are linked. These factors are also linked with the gametophyte factor Ga with a crossing-over value of 38.72 for the anther color (Br br) and of 36.80 for the pericarp color (W w). Thus, there are only two possibilities for the linear arrangement of these three genes, namely, W Ga br and Ga W br. If the former be the case, the linkage relation between the W and br should be loose. However, it is not so judging from the F_2 data (Table 13). On the other hand, their relation seems to be quite intimate showing the order of the genes to be Ga W br. As the cross-

TABLE 13.—*Segregation for anther and pericarp color in the F_2 generation.*

Anther color	Pericarp color	Observed frequency
Brown	White	641
Brown	Black	226
White	White	379
White	Black	4
Total...............		1,250

Now let: p = ratio of non-crossing over gametes; q = ratio of gametes, crossing over between Ga and W br; q′ = ratio of gametes, crossing over between br and Ga, W; q″ = ratio of gametes, crossing over between W and Ga, br; x = ratio of functional Ga pollen; 1-x = ratio of functional ga pollen.

Then, $2(p + q + q' + q'')^2 = N$, the total population of the F_2 generation.

ing-over value between Ga and br is larger than that between Ga and W, it seems to be untenable to adopt such a linear order as Ga br W.

By means of the checkerboard method it is easy to derive the formulae for the expected frequencies in terms of p, q, q′, q″, and x. By equating the formulae each with its corresponding observed frequency, the unknowns may be solved by solving the simultaneous equations. However, this cannot be done without assuming a value for x. It is possible to represent the p, q, q′, and q″ in terms of x alone as follows:

$p = (21.9211x-7.9007)/(2x-1)$; $q = (21.9211x-14.0207)/(2x-1)$; $q' = (3.0789x-1.2993)/(2x-1)$; $q'' = (3.0789x-1.7793)/(2x-1)$.

As q″ represents the ratio of double crossing over, then the formula of coincidence can also be derived in terms of x alone, as follows:

$$\text{Coincidence} = \frac{q''}{(q+q'')\,(q'+q'')/25} = \frac{(50x-25)\,(3.0789x-1.7793)}{(25x-15.80)\,(6.1578x-3.0786)}.$$

When x, the functional Ga gamete, varies from 0.50 to 1.00, the calculated coincidence is as follows:

x	Coincidence
0.50	0.0000
0.60	−0.6898
0.70	1.7950
0.80	1.3218
0.90	1.2017
1.00	1.1469

Not all these values are reliable, but the last one, 1.1469, based on x equal to 1.00 seems to be closer to unity. There are possibly three causes for the numercial value of coincidence exceeding unity, *viz.*, (a) the error of sampling, (b) the double-crossing over having taken place between Ga and br region, and (c) the occasional failure of synapsis of the homologous parts of the chromosome concerned. If x be adopted as unity on the assumption that no ga pollen is functional, the four unknowns may be calculated with the following values:

$$p = 14.0204$$
$$q = 7.9004$$
$$q' = 1.7796$$
$$q'' = 1.2996$$

Converting these values to the percentage of crossing-over, we obtain:

Noncrossing-over	56.08%
Crossing-over in the first region	31.60%
Crossing-over in the second region	7.12%
Double crossing-over	5.20%

Then the linear order of the three genes may be mapped in the following diagram:

$$\text{Ga} \xrightarrow{36.80} \text{W} \xrightarrow{12.32} \text{br}$$

For the F_3 generation, only such F_2 plants with brown anther and white pericarp were selected. The F_3 data are presented in Table 14. The expected frequency may be calculated by the formulae which can be easily derived by means of the checkerboard diagram of F_2 genotypes. The observed frequencies fit the calculated ones rather closely with a P value of 0.277.

TABLE 14.—*Segregation for anther and pericarp color in the F_3 generation.*

Anther color	Pericarp color	Observed	Calculated	Ratio	Formula
Segregating	Segregating	55	53.51	490.0035	$2q'q''+2pq+q'^2+q^2+p^2+q''^2$
Segregating	Nonsegregating	12	8.97	82.1819	$2pq'+pq''+qq'$
Nonsegregating	Segregating	3	6.92	63.3373	$2qq'+qq''+pq'$
Nonsegregating	Nonsegregating	0	0.60	5.4798	$qq'+q'^2$
Total		70	70.00		

$X^2=3.886$ $P = 0.277$.

LINKAGE RELATION BETWEEN PLANT COLOR AND BRISTLE COLOR

The plant color types were classified together with the bristle color and the resultant frequencies obtained are shown in Table 15.

TABLE 15.—*Segregation for plant color and bristle color in the F_2 generation.*

Plant color	Bristle color	Observed frequency	Formula
Purple	Purple	696	$\alpha(x+y) + ex$
Purple	Green	4	ey
Light purple	Purple	211	$\beta(x+y) + hx$
Light purple	Green	19	hy
Green	Purple	294	$(\alpha+\beta)(y+z) + (e+h)y$
Green	Green	26	$(e+h)z$
Total		1,250	$(\alpha+\beta+e+h)(x+2y+z)$

It can be noticed at once that purple plants did not always have colored bristles nor did green plants necessarily have green bristles. It seems, therefore, that the factors determining the color types for the plants and the bristles are linked. Accordingly, it is assumed that the genes In, Pr_1, and Pr_2 are located in one chromosome and P and Pr_3 in another. From this assumption, let a, b, c, d, e, f, g, and h be the frequencies for the phenotypes In Pr_1 Pr_2, in Pr_1 Pr_2, In pr_1 Pr_2,

In Pr_1 Pr_2, In pr_1 pr_2, in Pr_1 pr_2, in pr_1 Pr_2, and in pr_1 pr_2, respectively, and x, y, y, and z be the ratio for the other phenotypes P Pr_3, P pr_3, p Pr_3, and p pr_3, respectively. As stated before, in the presence of any of the triplicate factors Pr_1, Pr_2, or Pr_3, the bristle color would be purple. Hence, neither a, c, and d nor b, f, and g can be differentiated from one another. Thus, let $\alpha = a+c+d$ and $\beta = b+f+g$. Then, the theoretical formulae for the frequencies of phenotypes can be written as shown in Table 15. By equating each formula with its corresponding observed frequency, and solving the simultaneous equations, the solutions are obtained as follows:

$$\begin{aligned} \alpha &= 902.00 & \quad x &= 0.6356 \\ \beta &= 150.57 & \quad y &= 0.1177 \\ e &= 33.98 & \quad z &= 0.1330 \\ h &= 161.43 \end{aligned}$$

Then let p, q, q′, and q″ be the proportion of gametes with the constitution In Pr_1 Pr_2, or in pr_1 pr_2, In Pr_1 pr_2, or in pr_1 Pr_2, In pr_1 Pr_2, or in Pr_1 pr_2, and In pr_1 pr_2, or in Pr_1 Pr_2, respectively. From these assignments, we can formulate α, β, e, and h in terms of p, q, q′, and q″ readily.

$$\alpha = 3p^2 + 6pq + 6pq' + 4pq'' + 6qq' + 6qq'' + 6q'q'' + 3q'^2 + 2q''^2 + 3q^2$$
$$\beta = 2pq + 2pq' + 2pq'' + 2qq' + 2qq'' + 2q'q'' + q'^2 + q''^2 + q^2$$
$$e = 2pq'' + q''^2$$
$$h = p^2$$

From the last two equations p and q″ can be solved at once.

$$p = 12.7055$$
$$q'' = 1.2734$$

It seems to be impossible to solve the other two equations for the values of q and q′, since these two equations are equivalent in respect to q and q′. However, supposing there is no interference, the coincidence, therefore, would be unity. There are two possibilities for the linear order of the three genes, namely, In is located either on the one side of Pr_1 and Pr_2, or between them. In the second possibility, q″ will be the ratio of gamete that is the result of double crossing over. For $p+q+q'+q'' = 1/2\sqrt{N}$ or 17.6777 (N, the total population of the F_2) and $q+q'$ will be $17.6777-(p+q'')$ or 3.6988. This possibility is excluded for q″ is too large for a double crossing-over value. In the first possibility, q′ will be the ratio of gamete that is the result of double crossing-over. Then,

$$\text{Coincidence} = \frac{q'}{\frac{(q+q')\,(q''+q')}{17.6777}} = 1$$

$$q' = 0.3370 \qquad \text{and} \qquad q = 3.3618$$

By converting the values of p, q, q′, and q″ into percentage of crossing over, we get:

Non-crossing over (p)	71.87%
Crossing over between Pr_1 and Pr_2 (q)	19.02%
Double crossing over (q′)	1.91%
Crossing over between In and Pr_1 (q″)	7.20%

Then the order of these three loci will be:

$$\text{In} \overset{9.11}{\text{———}} Pr_1 \overset{20.93}{\text{————}} Pr_2$$

For the present calculation the total crossing-over percentage between Pr_1 and Pr_2 is 20.93 with a difference of only 0.12 from the value, 20.81% that is presented earlier.

Now let r and s be the proportion of gametes with the constitution P Pr_3 or p pr_3 and P pr_3 or p Pr_3 respectively (parental and recombination respectively). Thus, x, y, and z can be formulated in terms of r and s in a like manner.

$$4x = 3r^2 + 4rs + 2s^2$$
$$4y = s^2 + 2rs$$
$$4z = r^2$$

By means of Fisher's maximum likelihood method, the values of r and s are solved to be 0.7291 and 0.2709 respectively. Thus, the percentage of crossing-over between P and Pr_3 is 27.09.

In the F_3 generation, plant and bristle color were observed simultaneously. For the linkage relation between these two characters as just calculated above is quite complex, thus more complex F_3 data are to be expected. On the one hand, there are four kinds of segregating lines for the plant color, and on the other, there are seven for the bristle color. Altogether, the possible segregating types for these two characters in combination will be 28, but actually about 16 types were realized. As the segregating types for bristle color are too complex to be handled adequately, only two classes, segregating and nonsegregating, are used in combination with the four segregating types for plant color. The results are shown in Table 16.

The ratio is calculated on the assumption from the linkage values as having been computed from F_2 data. As the observed frequencies of segregating and nonsegregating lines of the bristle color deviate significantly from the expectation, the discrepancy also will be significant when the segregating types of the plant color are included. The cause of this disparity for the F_3 segregation of bristle color is not yet known. Nevertheless, when the frequencies of combination types alone are to be tested, the disparity due to the bristle color alone now may be disregarded by using in their stead the observed line numbers in F_3 for computing the expected frequencies. The observed frequencies fit the expected ones very well when the bristle color is segregating, but a poor fit is obtained for those not segregating. Nevertheless, the X^2 test for these two classes put together is none too large, with a P value of 0.08 (Table 16).

TABLE 16.—*Segregation for the plant color and bristle color in the F_3 generation.*

Plant color	Observed	Calculated	Ratio
Bristle Color Segregating			
Segregating for purple, light purple and green	32	34.58	191.0420
Segregating for purple and light purple.....	13	10.17	56.1651
Segregating for purple and green..........	4	3.29	18.1641
Nonsegregating...................... ..	0	0.96	5.3179
Total...............................	49	49.00	
Bristle Color Nonsegregating			
Segregating for purple, light purple and green	3	5.82	118.0157
Segregating for purple and light purple.....	1	4.87	99.4927
Segregating for purple and green...........	10	6.75	137.9274
Nonsegregating.........................	7	3.56	72.7781
Total...............................	21	21.00	

$X^2 = 11.424$ $n = 6$ $P = 0.08$

Moreover, the bristle and plant color were classified together in individual F_3 lines in which both characters were segregating. The data are presented in Table 17. The calculated frequency of each individual line is based upon the crossing-over values of F_2 generation. From Table 17, it is evident that by direct comparison, in a majority of cases there is a reasonable agreement between the observed and the calculated frequencies, although the respective goodness of fit is not tested.

Hence, it may be concluded that the hypothecated complex linkage relation between the plant color and bristle color thus proved by the F_3 data is acceptable.

LINKAGE RELATION BETWEEN SEEDCOAT COLOR AND THE P PR_3 GROUP

When the seedcoat color is classified together with the plant color, the result shows that these two characters are correlated. By calculation it is revealed that one of the three seedcoat color factors is linked with the purple pigmentation factor of plant color with a crossing-over percentage of 19.37 (calculated by means of the least square method). However, which one of the seedcoat color factors is linked with the factor P is difficult to determine, since none of the possible cases can sustain the X^2 test without a significant discrepancy between the observed and calculated frequencies (Table 18).

It must be pointed out here that the differentiation between the color types tawny buff, and korra buff is not easy, especially when the color tone has been partly altered by exposure to dampness. Faulty classification is thus in some cases unavoidable. This seems to be the cause of the difficulty encountered above. However, the difference between the black coloration from tawny buff and korra buff is very distinct. Although no definite assignment can be adopted among the seedcoat color factors in the linkage relation with the plant color factor P, it is certain that they are linked. It can be

TABLE 17.—*Segregation for bristle color and plant color in the F_3 individual lines.*

Line No.	X Y	Xy	xY	xy	Plant color	Bristle color	Linkage relation
1257 Obs. Cal.	70 76.30	15 4.70	1 4.70	22 22.30	3P : 1LP	3P : 1G	In 9.11 Pr_1
1262 Obs. Cal.	52 56.53	5 3.48	2 3.48	21 16.52	3P : 1LP	3P : 1G	In 9.11 Pr_1
1278 Obs. Cal.	81 74.62	0 1.10	12 20.03	8 5.21	3P : 1LP	15P : 1G	In 9.11 Pr_1
1290 Obs. Cal.	84 79.12	0 1.16	13 21.23	10 5.53	3P : 1 LP	15P : 1G (Indep.)	In 9.11 Pr_1
1296 Obs. Cal.	70 70.25	0 1.03	19 18.85	6 4.91	3P : 1 LP	15P : 1G (Indep.)	In 9.11 Pr_1
1304 Obs. Cal.	86 89.41	0 1.31	24 23.99	11 6.25	3P : 1 LP	15P : 1G (Indep.)	In 9.11 Pr_1
1256 Obs. Cal.	57 65.71	0 4.04	28 27.29	39 26.96	9P : 7 others	3P : 1G	In 9.11 Pr_1
1258 Obs. Cal.	87 79.59	0 5.00	28 33.45	37 33.04	9P : 7 others	3P : 1G	In 9.11 Pr_1
1260 Obs. Cal.	69 64.65	1 3.98	19 26.85	33 26.52	9P : 7 others	3P : 1G	In 9.11 Pr_1
1288 Obs. Cal.	66 69.44	0 4.27	28 28.84	37 28.49	9P : 7 others	3P : 1G	In 9.11 Pr_1
1297 Obs. Cal.	71 65.71	0 4.04	25 27.29	28 26.96	9P : 7 others	3P : 1G	In 9.11 Pr_1
1269 Obs. Cal.	51 55.21	0 0.50	41 37.64	7 5.69	9P : 7 others	15P : 1G (Indep.)	In 9.11 Pr_1
1272 Obs. Cal.	23 26.75	0 0.24	22 18.24	3 2.76	9P : 7 others	15P : 1G (Indep.)	In 9.11 Pr_1
1303 Obs. Cal.	61 66.89	0 0.61	49 45.61	10 6.89	9P : 7 others	15P : 1G (Indep.)	In 9.11 Pr_1
1308 Obs. Cal.	92 93.64	1 0.86	60 63.86	15 9.64	9P : 7 others	15P : 1G (Indep.)	In 9.11 Pr_1
1320 Obs. Cal.	55 49.59	0 0.45	27 33.81	7 5.11	9P : 7 others	15P : 1G (Indep.)	In 9.11 Pr_1
1261 Obs. Cal.	85 78.78	0 2.96	11 13.18	13 14.07	3P : 1LP	15P : 1G (Coupling)	In 9.11 Pr_1 20.93 Pr_2
1277 Obs. Cal.	99 88.90	3 3.33	7 14.88	14 15.88	3P : 1LP	15P : 1G (Coupling)	In 9.11 Pr_1 20.93 Pr_2
1287 Obs. Cal.	71 65.05	0 2.44	3 10.89	16 11.62	3P : 1LP	15P : 1G (Coupling)	In 9.11 Pr_1 20.93 Pr_2

TABLE 17.—*Concluded.*

Line No.	X Y	Xy	xY	xy	Plant color	Bristle color	Linkage relation
1301 Obs. Cal.	33 33.97	0 1.28	8 5.68	6 6.07	3P : 1LP	15P : 1G (Coupling)	In 9.11 Pr_1 20.93 Pr_2
1309 Obs. Cal.	48 46.26	0 1.74	8 7.74	8 8.26	3P : 1LP	15P : 1G (Coupling)	In 9.11 Pr_1 20.93 Pr_2
1316 Obs. Cal.	81 78.78	1 2.96	12 13.18	15 14.07	3P : 1LP	15P : 1G (Coupling)	In 9.11 Pr_1 20.93 Pr_2
1253 Obs. Cal.	58 52.04	0 1.95	28 28.96	10 13.05	9P : 7 others	15P : 1G (Coupling)	In 9.11 Pr_1 20.93 Pr_2
1268 Obs. Cal.	44 39.03	2 1.47	15 21.72	11 9.79	9P : 7 others	15P : 1G (Coupling)	In 9.11 Pr_1 20.93 Pr_2
1270 Obs. Cal.	54 63.97	2 2.40	47 35.59	15 16.04	9P : 7 others	15P : 1G (Coupling)	In 9.11 Pr_1 20.93 Pr_2
1274 Obs. Cal.	33 32.52	0 1.22	17 18.11	10 8.15	9P : 7 others	15P : 1G (Coupling)	In 9.11 Pr_1 20.93 Pr_2
1285 Obs. Cal.	61 60.19	0 2.26	33 33.49	17 15.09	9P : 7 others	15P : 1G (Coupling)	In 9.11 Pr_1 20.93 Pr_2
1306 Obs. Cal.	48 46.06	0 1.73	20 25.63	17 11.55	9P : 7 others	15P : 1G (Coupling)	In 9.11 Pr_1 20.93 Pr_2
1311 Obs. Cal.	81 82.40	0 3.10	51 45.85	20 20.66	9P : 7 others	15P : 1G (Coupling)	In 9.11 Pr_1 20.93 Pr_2
1313 Obs. Cal.	44 46.06	3 1.73	24 25.63	14 11.55	9P : 7 others	15P : 1G (Coupling)	In 9.11 Pr_1 20.93 Pr_2
1314 Obs. Cal.	68 71.05	0 0.40	56 51.03	3 4.56	9P : 7 others	63P : 1 G (Coupling)	As the F_1
1267 Obs. Cal.	89 89.18	0 0.81	25 26.14	6 3.87	3P : 1LP	63P : 1G (Coupling)	In 9.11 Pr_1 20.93 Pr_2
1271 Obs. Cal.	81 80.26	1 0.73	22 23.52	4 3.49	3P : 1LP	63P : 1G (Coupling)	In 9.11 Pr_1 20.93 Pr_2
1298 Obs. Cal.	59 51.25	0 0.47	8 15.02	2 2.23	3P : 1LP	63P : 1G (Coupling)	In 9.11 Pr_1 20.93 Pr_2
1305 Obs. Cal.	111 112.96	0 1.03	38 33.10	3 4.91	3P : 1LP	63P : 1G (Coupling)	In 9.11 Pr_1 20.93 Pr_2
1292 Obs. Cal.	76 69.04	0 0.18	49 52.66	2 1.17	9P : 7 others	15P : 1G (Repulsion)	In 9.11 Pr_1 20.93 Pr_2
1302 Obs. Cal.	88 91.27	0 0.23	33 27.39	1 1.10	9P : 7 others	15P : 1G (Repulsion)	In 9.11 pr_1 20.93 Pr_2

verified by testing the presence of linkage relation between the seedcoat color and bristle color, since it has been already proved that P is linked with Pr_3, one of the triplicate factors of the purple

TABLE 18.—*Segregation for the seedcoat color and plant color in the F_2 generation.*

	Seedcoat color			Total	Remarks
	Black	Tawny buff	Korra buff		
		Purple Plant Color			
Observed	346.00	88.00	266.00		
Calculated:	349.18	353.54			
Case 1*	——	46.10	307.44		
Case 2*	——	116.39	237.15		
Case 3*	——	69.53	284.01		
		Light Purple Plant Color			
Observed	131.00	31.00	68.00		
Calculated:	116.39	117.85			
Case 1*	——	15.37	102.48		
Case 2*	——	38.79	79.07		
Case 3*	——	23.18	94.67		
		Green Plant Color			
Observed	68.00	59.00	193.00	1250.00	
Calculated:	61.47	250.85		1249.28	$x^2=5.578$ P=0.357
Case 1*	——	114.21	136.64		$x^2=113.582$ P=0.000
Case 2*	——	20.49	230.36		$x^2=91.982$ P=0.000
Case 3*	——	82.97	167.88		$x^2=26.798$ P=0.000

*Case 1, B linked with P; Case 2, R or V ilinked with P; Case 3, B or R or Vi linked with P, and the tawny buff color is due to the presence of any one of these three factors.

coloration of the bristle. When the seedcoat color is compared with bristle color, the result shows an independent segregation, with a P value of 0.576. However, while the linkage relation inferred from the relations between the seedcoat color and plant color and plant color and bristle color is applied in the calculation of the expected frequencies, the agreement between the observed frequencies and the calculated ones is much closer, with a P value increasing to 0.803 (Table 19).

TABLE 19.—*Segregation for the seedcoat color and bristle color in the F_3 generation.*

	Purple bristle		Green bristle		Total	Remark
	Black seed-coat	Non-black seed-coat	Black seed-coat	Non-black seed-coat		
Observed	527.00	674.00	18.00	31.00	1250.00	
Calculated (Indep.)	506.67	694.33	20.67	28.33	1250.00	$x^2=2.007$ P=0.576
Caclulated (Linked)	510.85	689.64	16.19	32.60	1249.28	$x^2=0.983$ P=0.803 With a crossing over percentage 35.96% between Pr_3 and a factor of seedcoat color

From Table 19, it can be seen that the linkage relation between one of the seedcoat color factors and the gene Pr_3 is quite loose. The linear arrangement of these three factors may, therefore, be assigned as follows:

X $^{19.37\%}$ P $^{27.09\%}$ Pr_3, X being one of the seedcoat color factors.

This linkage relation is further tested by the F_3 segregations. There are 16 possible combinations for the segregating types of seedcoat color and plant color and 8 for seedcoat color and bristle color. For bristle color only two types, segregating and nonsegregating, need to be taken into consideration. The calculations of the expected frequencies are based upon the percentages of crossing-over computed as from the F_2 segregation. In both cases, the observed frequencies are all in good agreement with the calculated ones (Table 20 and 21).

However, when the calculations are based upon the independent relation between the seedcoat color and the P-Pr_3 linkage group, the fit between the calculated and observed frequencies in the both cases is still quite good, although both with a smaller P value. It is concluded, therefore, that the number of lines in the F_3 generation is not large enough so as to discern their relationships definitely.

TABLE 20.—*Segregation for the seedcoat color and plant color in the F_3 generation.*

Plant color segregated for	Seedcoat color segregated for	Observed	Calculated	
			Independent	Linked
9P : 7 others......	27 black : 37 others	10	8.83	10.30
9P : 7 others......	9 black : 7 others	16	13.24	12.64
9P : 7 others......	3 black : 1 other	6	6.62	4.91
9P : 7 others......	All black	2	1.10	0.59
3P : 1LP..........	27 black : 37 others	1	4.41	2.34
3P : 1LP..........	9 black : 7 others	8	6.62	7.21
3P : 1LP..........	3 black : 1 other	4	3.31	5.45
3P : 1LP..........	All black	0	0.55	1.22
3P : 1 green.......	27 black : 37 others	5	4.41	5.15
3P : 1 green.......	9 black : 7 others	7	6.62	6.32
3P : 1 green.......	3 black : 1 other	1	3.31	2.46
3P : 1 green.......	All black	0	0.55	0.29
All purple.........	27 black : 37 others	0	2.20	1.17
All purple.........	9 black : 7 others	4	3.31	3.60
All purple.........	3 black : 1 other	3	1.65	2.73
All purple.........	All black	0	0.27	0.61
Total............................		67	67.00	66.99
			$X^2 = 11.122$ $P = 0.742$	$X^2 = 10.059$ $P = 0.814$

LINKAGE RELATION BETWEEN OTHER CHARACTERS

All possible paired combinations of the eight characters studied were considered in the F_2 generation. In addition to the three linkage groups mentioned above, there are four combinations, e.g., seed-

coat color and pericarp color, pericarp color and endosperm color, plant color and seedling growth habit, and plant color and anther color, that show discrepancy from independent segregation in various degrees. But in the F_3 progenies, they are all proved to be mutually independent whether tested by individual lines or by combining groups of segregating types. In summing up, it can be concluded that there seem to be no linkages among the character factors other than the three linkage groups mentioned above. The detailed data in regard to these are not presented here.

TABLE 21.—*Segregation for the seedcoat color and bristle color in the F_3 generation.*

Seedcoat color segregated for	Observed	Calculated	
		Independent	Linked
Bristle Color Segregated			
27 black : 37 others	13	13.91	12.84
9 black : 7 others	23	20.89	20.89
3 black : 1 other	10	10.44	11.26
All black	1	1.74	2.01
Total	47	47.01	47.00
Bristle Color Nonsegregated			
27 black : 37 others	3	5.93	5.08
9 black : 7 others	12	8.89	8.89
3 black : 1 other	4	4.44	5.08
All black	1	0.74	0.95
Total	20	20.01	20.00
		$X^2=3.280$ $P=0.772$	$X^2=3.037$ $P=0.804$

DISCUSSION

Sterility seems to be encountered frequently in interspecific hybrids. In the present case partial sterility of both pollen and seed are met with. However, the chromosome pairing of the hybrid at meiosis is normal, so that the partial sterility appears to be due to unknown causes and not to irregularity of chromosomal distribution. It is fortunate that in the material studied partial sterility did not disturb the normal segregation of the factors studied in either the F_2 or F_3 progenies. This makes the present genetic studies of the interspecific hybrid possible and rather simple.

The presence of triplicate factors for the manifestation of the purple bristle color, two of which are linked, is of some significance with regard to the evolution of the basic chromosome number of the genus *Setaria*. The basic number so far studied in the *Setaria* species is nine. Any *Setaria* species which has nine pairs of chromosomes may be regarded as the prototype of the genus so far as chromosome number is concerned. *Setaria italica* and *S. viridis* both have nine pairs of chromosomes and, therefore, are prototypes of the *Setaria* species, although their morphological characters are quite advanced

in comparison with the other species. The presence of triplicate factors indicates that the basic number nine is most probably derived from a number smaller than nine. Moreover, from the present evidences it may be inferred that one of the nine basic chromosomes is not only a duplicate of another but also has a region duplicated. This duplicated region may be either due to the result of unequal crossing-over with its homologue or translocated from its duplicate one. No matter what its origin, it may be concluded that nine is a secondary number which is originated from a lower one. Perhaps such might be found in genera related to *Setaria*.

Either from cytological observations or by genetical analysis of the hybrids it can be concluded with certainty that the two species *S. italica* and *S. viridis* are closely related. In the *italica* parent, of 15 genes studied only 2, the white pericarp color and gametophyte factor Ga, are dominant, and the other 13 are recessive. This indicates that *S. italica* may have originated from *S. viridis* through successive mutations. Although there are a great number of genic differences between these two species, the basic quality of their corresponding chromosomes has not altered much because close pairing occurred in the hybrid at meiosis. This suggests that the cultivated millet *S. italica* was evolved from its progenitor *S. viridis*, the wild green foxtail, only very recently The intimate association of their geographical distribution may be looked upon as a further proof of this possibility.

SUMMARY

A cross was made between *S. italica*, the cultivated millet, and *S. viridis*, the wild foxtail, both of which have nine pairs of chromosomes. The pairing of the chromosomes in the F_1 hybrid seemed to be normal. The hybrid, however, had about 70% pollen sterility.

Eight qualitative characters were studied in this cross. The F_1 hybrid resembled the *viridis* parent for all characters studied except pericarp color. Altogether 15 gene differences with three linkage groups were revealed in the F_2 generation and these were confirmed in the F_3 generation. The three linkage groups are mapped as follows:

In	Pr_1	Pr_2
0	9.11	30.04

X	P	Pr_3
0	19.37	46.46

X may be B, Vi, or R.

Ga	W	br
0	36.80	49.12

Other genes studied seem to be inherited independently of these three groups and of one another.

S. viridis is concluded to be the probable immediate progenitor of the cultivated millet, *S. italica*.

The genes found in this interspecific cross are tabulated as follows:

Symbol of gene	Character affected
R, Vi, B	Black seedcoat color, R and Vi complementary for tawny buff, B supplementary for black
Y	Yellow endosperm
S, H	Complementary for seed shattering
Ps	Prostrate seedling
P	Purple plant color
In	Intensifier of P
Pr_1, Pr_2, Pr_3	Triplicate factors for purple bristle
Br	Brown anther color
W	White pericarp color
Ga	Gametophyte factor for differential pollen tube growth

LITERATURE CITED

1. EMERSON, R. A. Relation of the differential fertilization genes Ga ga to certain other genes of the Su-Tu linkage group of maize. Genetics, 19:137–156. 1934.
2. KRISHNASWAMI, N., AND RANGASWAMI AYYANGAR, G. N. Chromosome numbers in some Seteria species. Current Science, 3:559–560. 1935.
3. LI, H. W., MENG, C. J., AND LIU, T. N. Problems in the breeding of millet, *Setaria* (L.) Beauv. Jour. Amer. Soc. Agron., 27:963–970. 1935.
4. ———, ———, ———. Genetic studies with foxtail millet, *Setaria italica* (L.) Beauv. Jour. Amer. Soc. Agron., 32:426–438. 1940.
5. MANGELSDORF, P. C., AND JONES, D. F. The expression of Mendelian factors in the gametophyte of maize. Genetics, 11:423–455. 1926.
6. PIPER, C. V. Forage Plants and Their Culture. New York: MacMillan Co. 1924.
7. RANGASWAMI AYYANGAR, G. N. Recent work on the genetics of millet in India. Madras Agr. Jour., 22:1–11. 1934.
8. ———, NARAYANA, T. R., NARAYANA RAO, T., AND SESHADRI SARMA, P. Inheritance of characters in *S. italica* (Beauv.), the Italian millet. Part 7. Plant purple pigmentation. Agr. Sci., 5:1–19. 1935.
9. ———, AND HARIHANAN, P. V. The occurrence and inheritance of yellow colored anthers in the Italian millet, *S. italica* (Beauv.). Madras Agr. Jour., 24:1. 1936.

COTTON ROOT DEVELOPMENT IN RELATION TO NATURAL AERATION OF SOME MISSISSIPPI BLACKBELT AND DELTA SOILS[1]

O. A. LEONARD[2]

THE agriculture of the Missippi-Alabama blackbelt soils consists mainly of cotton and Johnson grass meadows for hay. Originally, this was a natural prairie section. Because of its high content of clay, the soil is difficult to handle and the crop yields are often poor; nevertheless, with proper management the yields are good.

The agriculture of the alluvial delta area of Mississippi consists mainly of row crops, of which cotton is the most important. Originally, the area was covered with a forest consisting of broad leaf trees and of cyprus. The sandier soils are easily handled and the crop yields are generally good. The heavy clay soils are difficult to handle and the crop yields are often poor.

It was obvious that wet subsoils and poor aeration were factors limiting crop production on the soils derived from Selma Chalk in the Mississippi-Alabama blackbelt. The heavy clay soils in the Mississippi Delta area were believed to be less productive than similar soils containing more sand because of poor internal drainage and, consequently, poor aeration. The sandier soils of the Mississippi Delta were considered poorly aerated during prolonged rainy seasons.

Imperfect drainage affects plant growth chiefly in the manner in which it affects soil aeration. Factors that influence the aeration of soils have been excellently reviewed by Clements (7)[3] and by Rommel (17). Only a limited amount of work has been done on the effect of soil aeration on cotton root growth. Balls (1) in Egypt found that cotton roots died, apparently from asphyxiation, when the water table rose. Cannon and Free (6), in laboratory studies, found that cotton roots did not grow when oxygen values in the soil approached 1% oxygen or less. The minimum percentage of oxygen for cotton root growth was somewhat variable and, also, was influenced by soil temperature.

The original purpose of the investigation reported here was to determine the influence of tillage on cotton root growth and soil aeration under Houston clay and soils of the Sarpy series. The influence of tillage, but not of soil aeration, has already been reported for Houston clay (12).

It was necessary to have a general picture of the seasonal changes in cotton root growth and soil aeration in order to evaluate properly the effect of tillage treatments. After the study was underway, the importance of aeration on the presence and severity of the cotton-

[1]Published with the approval of the Director, Mississippi Agricultural Experiment Station, State College, Miss. Journal paper No. 86, new series. Received for publication August 28, 1944.

[2]Plant Physiologist. The author wishes to thank Dr. J. A. Pinckard of the Plant Pathology Department for his help and cooperation in the work reported in this paper.

[3]Figures in parenthesis refer to "Literature Cited", p. 70.

wilt-nematode complex was indicated by the natural distribution of the disease-infested areas.

METHODS OF STUDY

MISSISSIPPI-ALABAMA BLACKBELT SOILS

The soils of this area were represented by Houston clay at the West Point Branch Experiment Station near West Point, Miss. Soils of the Houston series are upland soils, and are derived from the weathering of calcareous clays, chalk beds, and soft limestone.

SOILS OF THE MISSISSIPPI RIVER ALLUVIAL AREA

The soils of this area were represented by Sarpy clay and Sarpy fine sandy loam on the Delta Branch Experiment Station at Stoneville, Miss., and by some Sarpy soils on the Delta and Pine Land Company plantation at Scott, Miss. Soils of the Sarpy series are alluvial bottom soils found in the Mississippi Valley that have been affected by changing rivers or bayous. The above is according to the old classification, but will probably be changed by the new scheme.

RUSTON SANDY LOAM

Ruston sandy loam under cotton was studied on the South Mississippi Branch Experiment Station at Poplarville, Miss. Results from this soil will be referred to only briefly, and all further reference to it will be in connection with presentation of data and discussion.

PLOT TREATMENTS FROM WHICH SOIL AIR DATA ARE REPORTED

D. and P.L.11A variety of cotton was grown at West Point, Miss., on Houston clay. Four hundred pounds of 6–8–4 fertilizer were used per acre each year. The plots reported received neither seedbed preparation nor cultivation, except during 1941, when the plots were both prepared and cultivated. In studies not reported, neither seedbed preparation nor cultivation had any influence on aeration or root growth below a depth of 6 inches. The degree of aggregation of the top soil, rather than the specific influence of tillage, was correlated with the development of small cotton roots.

Express variety of cotton was grown on Sarpy fine sandy loam in 1941 and Delfos 3506 in 1942 and 1943. In 1941, vetch was plowed under flat and not bedded. In 1942, 12 tons of stable manure per acre were placed beneath the cotton rows and in 1943 no fertilizer of any kind was used. The plots were bedded in 1942 and 1943. The plots for all three years received normal cultivation.

DEPTH OF THE WATER TABLE ON HOUSTON CLAY

The depth of the water table was determined weekly from early spring through midsummer by measuring the distance to the water from the surface of the ground in 6-inch tile wells established at six locations uniformly distributed around the edge of the experimental field.[4]

SOIL AIR ANALYSES

The method of obtaining samples of air from soils was similar to the method described by Boynton and Reuther (5). Air well tubes were assembled by connecting copper tubing (5-mm outside diameter) to short Pyrex cylinders (19-mm outside diameter) by means of one-hole rubber stoppers. The Pyrex cylinders were filled with glass wool to prevent soil from plugging the copper tubing. The upper ends of the copper tubing were closed with rubber caps. The air wells, thus assembled, were placed in auger holes in the cotton rows and soil packed firmly around the copper tubing. It was possible to cultivate the cotton without disturbing the air wells.

---

[4]The author is indebted to T. N. Jones and I. E. Hamblin for obtaining the water table data.

Soil air data are considered quite satisfactory under Sarpy fine sandy loam, but only moderately so under Houston clay. Houston clay shrinks and cracks upon drying. The cracks may not entirely close when the soil again becomes saturated; thus, the soil air analyses under Houston clay probably give oxygen values that are too high.

A portable gas analyses apparatus, with a simple mercury suction pump, was carried into the field wherever the air wells were present.

In 1941, 100 cc of air were discarded before samples of soil air were analyzed. Because of great variability in analyses on Houston clay and because successive samples gave successively higher oxygen readings, especially at shallow depths, indicating contamination from large soil cracks and crayfish holes, the discard in 1942, 1943, and 1944 was reduced to about 20 cc. Two or three samples, nevertheless, were usually drawn and analyzed from the same wells.

MECHANICAL ANALYSES, pH, AND QUICK TESTS ON SOILS

The mechanical composition of the soils studied was determined[5] according to the method of Bouyoucos. Although this method may be open to certain objections, it appeared to be suitable for the purposes of this study.

The soil pH was determined with the Beckman glass electrode.

The methods employed for making quick tests of the soil were the same as those reported by Miles (16).

ROOT STUDIES

The roots were examined in every case by digging rectangular pits to one side of the cotton rows and exposing the roots by working inward, by using an ice pick and by washing with power sprayers.

Quantitative studies on root distribution were made by removing the roots from a given volume of soil by washing the soil through a 14-mesh screen. The roots were picked off the screen with forceps, separated into different sizes, dried, weighed, and calculated as percentage distribution of roots of different sizes. The results on root distribution (0–1 mm diameter only) are illustrated diagrammatically in the various figures. The entire roots system at two stages of growth is shown in one figure.

RESULTS AND DISCUSSION

DESCRIPTION OF SOILS

Since the primary purpose of this paper is to show the influence of aeration on cotton root growth and distribution, the mineral nutrition and other data will be considered only insofar as they may aid in the interpretation of the soil air data.

A general description of the soils and cotton root distribution (roots of 0–1 mm diameter only) is given in Table 1.

The clay content of the soils was greatest in Houston clay, next in Houston clay (shallow phase), and least in Sarpy fine sandy loam.

The Houston clay was alkaline and tended to become more alkaline with depth, especially on the location where chalk was only 6 feet deep. Sarpy fine sandy loam from the locations studied became alkaline with depth, the pH ranging from 6.3 to 8.2.

Nitrates were low in all of the subsoils, according to quick tests. Evidence from other sources indicated nitrogen to be, at times, quite deficient in the subsoil of Houston clay. Nitrogen was the first limiting nutrient in both Sarpy surface and subsoils (pot tests).

Available phosphorus was very low in the subsoil of Houston clay, especially between the depths of 1 and 3 feet. Phosphorus was quite

[5]The author wishes to thank Marvin Gieger of the Mississippi Experiment Station Chemistry Department for making the mechanical analyses.

high under Houston clay next to Selma chalk. Sarpy fine sandy loam contained ample phosphorus at all depths. Evidently, phosphorus could not have been a factor limiting root growth except in Houston clay between the depths of 1 and 3 feet. In pot tests phosphorus was found to be the first limiting factor affecting the growth of cotton in the air-dried subsoil of Houston clay.

Potassium did not appear to be a limiting factor affecting root or top growth in Sarpy fine sandy loam. Evidence from pot tests

TABLE 1.—*Color of the soil, distribution of feeder roots (0–1 mm diameter), pH mechanical composition, and plant food as revealed by quick tests at different depths on Houston clay, Houston clay (shallow phase), and Sarpy fine sandy loam.*

Depth in feet	Soil color	Feeder root distribution*, %	pH	Mechanical composition, %†			Quick tests		
				Sand	Clay	Silt	NO_3	PO_4	K
				Houston Clay					
0–1	Gray	56	7.9	19	42	39	Trace	Medium	Trace
1–2	Black	17	8.0	23	40	37	Low trace	0	Trace
2–3	Black	15	7.9	18	41	41	Low trace	0	Trace
3–4	Dark gray	10	8.0	20	41	39	Low trace	Trace	Trace
4–5	Dark gray	2	8.0	18	39	43	Low trace	Trace	Trace
5–6	Med. gray	0	8.0	18	38	44	Low trace	Trace	Trace
6–7			—‡	—‡	—‡	—‡			
				Houston Clay (shallow phase)					
0–1	Black	93	7.3	29	43	28	Trace	Medium	Trace
1–2	Black	3	7.4	26	44	30	Low trace	0	Trace
2–3	Dark gray	1	7.8	26	44	30	Low trace	0	0
3–4	Light gray	2	8.2	26	42	32	Low trace	Trace	Trace
4–5	Light gray	1	8.2	25	38	37	0	Medium	Trace
5–6	Light gray	0	8.2	26	39	35	Low trace	High	Trace
6–7			—§	—§	—§	—§			
				Sarpy Fine Sandy Loam (Site 1)					
0–1	Gray	38	6.5	32	58	10		Medium	Medium
1–2	Gray	20	6.6	33	58	9		Medium	Medium
2–3	Gray	19	7.0	34	58	8		Medium	Medium
3–4	Gray	19	7.6	35	57	8		Medium	High
4–5		4	—‡	—‡	—‡	—‡			
5–6		0	—	—	—	—			
				Sarpy Fine Sandy Loam (Site 4)					
0–1	Gray	36	6.7	35	59	6	Low trace	Medium	Medium
1–2	Gray	34	6.7	54	41	5	Low trace	Trace	Trace
2–3	Gray	16	6.7	70	28	2	Low trace	Medium	Trace
3–4	Gray	11	6.7	48	48	4	Low trace	Medium	Trace
4–5	Gray	2	7.7	38	58	4	Trace	Medium	Trace
5–6	Gray	1	8.2	30	67	3	Trace	Medium	Medium
6–7	———	0	—‡	—‡	—‡	—‡			

*Data on feeder roots taken during harvest directly beneath the cotton rows.
†Sand = 1.0–0.05 mm; silt = 0.05–0.005 mm; and clay = 0.005–0.000 mm.
‡Similar to above sample.
§Chalk.

indicated potassium not to be seriously limiting in Houston clay, although the leaf blades sometimes showed symptoms of potassium deficiency, especially when the cotton was fruiting.

According to quick tests and pot experiments, neither calcium nor magnesium were deficient in any of the soils studied. Studies on the undisturbed subsoils must be made before final conclusions can be drawn on the availability of nutrients.

A greater percentage of the feeder roots (0–1 mm diameter) were present in the first foot of soil under Houston clay than under Sarpy fine sandy loam. These data (Table 1) were obtained in the fall of the year. Cotton roots under Houston clay were found to be, in general, remarkably free from fungi and nematodes. Cotton roots under Sarpy fine sandy loam were attacked by both parasitic fungi and nematodes and the injury to roots seemed to increase with increasing sand content of the soil.

DEPTH OF WATER TABLE AND COTTON ROOT GROWTH ON HOUSTON CLAY

The data on fluctuations of the water table were obtained in 1939 and 1940. All of the water table wells, except well No. 4, were located in soil comparable to the location of Fig. 3, from which soil air readings were obtained.

The water tables were, for the most part, less than 3 feet deep until about August 1 (Fig. 1). The water tables in all wells were fairly similar, except for well No. 4 which was located on a slope where the Selma Chalk was only 6 feet deep.

Very few roots were deeper than 4 inches on August 3, 1939, although some roots grew laterally 42 inches. Vertically, a few roots were traced to a depth of 16 inches. After the water table dropped in August, the roots grew downward and had attained a depth of 4 feet in October (a large root of one plant followed a crayfish hole and was traced to a depth of 5 feet).

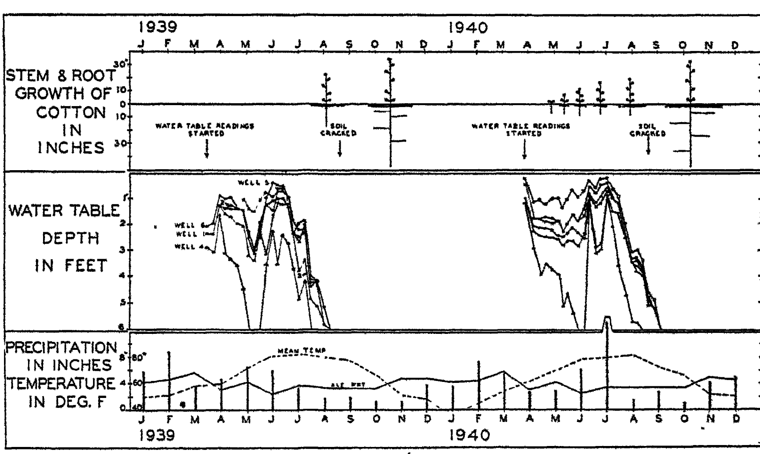

FIG. 1.—Relationship between the depth of the water table and the growth and distribution of cotton roots.

The maximum depth cotton roots found during 1940 was 8 inches (on the main part of the field), until after the water table dropped in August. The rainfall in June and July of 1940 was excessive. Again, after the water table dropped in August, as in 1939, the cotton roots grew downward to a depth of 4 feet in October.

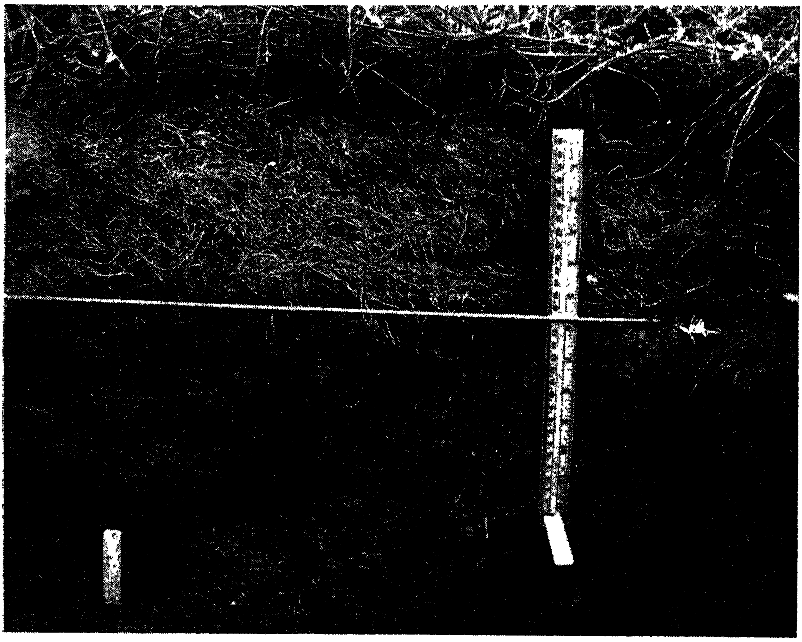

FIG. 2.—The distribution of vetch roots in Houston clay on April 16, 1944. A crayfish hole may be noted in the lower left. Depth of the water table was 17 inches.

A good correlation existed between the looseness of the soil and the abundance of roots. The loose soil varied between 3 and 6 inches deep. The roots developed first on the surface of the firm clods and subsoil before growing into such places. The relationship between looseness of the soil and the abundance of roots was noted not only for cotton growing on Houston clay, but also for vetch (Fig. 2), oats, corn, and soybeans.

AERATION AND ROOT GROWTH ON HOUSTON CLAY

A deficiency in oxygen in 1941 apparently prevented tap or secondary roots from growing deeper than 16 inches until after August 1 (Fig. 3). The soil oxygen remained at less than 1% at a depth of 16 inches until in August. After the soil became higher in oxygen in August, the tap root, or functionally similar roots, grew rapidly downward. It might be noted that practically all of the small roots were in the upper 6 inches of soil, even early in August. The distribution of roots probably gives a good indication on the aeration

conditions in most of the soil mass. Some roots followed cracks and crayfish holes and were able to penetrate deeper into the subsoil than could most of the roots. Such locations are likely much higher in oxygen than was most of the soil.

The 8-inch depth was only 2 or 3 inches below the loose well-aerated soil filled with roots, and the samples likely consisted of air from these layers rather than from the more compact layers below the wells. Nevertheless, occasionally, some wells located at this depth gave values as low as 1% oxygen.

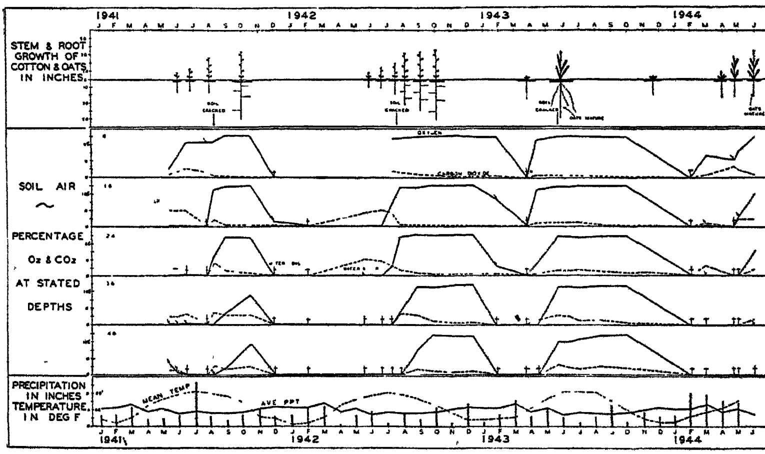

FIG. 3.—Relationship between the composition of the soil air and the growth and distribution of the roots (0–1 mm in diameter) of cotton and oats in Houston clay.

The improved root growth and aeration in the subsoil in August was a result of the soil becoming drier and cracking. The soil seemed to be fairly moist or wet until August 1.

About 50% of the small cotton roots were in the top 6 inches of soil in October. Whether the distribution of roots was solely the result of aeration factors could not be ascertained from data obtained in 1941.

The year 1942 was extremely dry, which contrasted with the studies made in previous years. Aeration was good from July on through the growing season at a depth of 16 inches. Most of the small roots were very shallow until in July when the subsoil became better aerated. After the subsoil became better aerated, root growth seemed to occur for a time about as well in the subsoil as in the surface soil. Eventually, however, root growth in the subsoil decreased, while in surface soil the roots continued to increase. The evidence suggested that factors in addition to aeration affected the pattern of root distribution vertically in the soil in the fall of the year.

The maximum depth obtained by cotton roots was usually around 48 to 50 inches.

Oats had a remarkable influence on improving the aeration of Houston clay in 1943. On May 22 the soil under oats was badly

cracked, while nearby soil under cotton was without cracks. The oat crop was almost mature at this time, with the leaves becoming yellow. Very large quantities of water must have been transpired by the oat crop. In 1944, more rain fell in the spring than in 1943 and kept the soil sufficiently wet and poorly aerated to prevent the oat roots from growing deeper than 20 inches, or the same depth they had attained before the soil had become poorly aerated in the late fall.

A deficiency in the subsoil of available phosphorus and nitrogen probably affected the distribution of roots on mature cotton and oat plants. Considerable numbers of roots were broken when the soil cracked; and this, no doubt, had some influence on the pattern in which roots were distributed. The roots, for the most part, appeared to be healthy and free from root parasites.

AERATION AND ROOT GROWTH ON HOUSTON CLAY (SHALLOW PHASE)

The aeration and root growth on Houston clay (shallow phase) were similar to those on Houston clay, except for minor differences (Fig. 4). A deficiency in oxygen at a depth of 16 inches seems to have prevented cotton roots from growing deeper than 16 to 18 inches, until in July 1942. In 1943, a fairly uniform development of roots occurred about the middle of June and was related to a

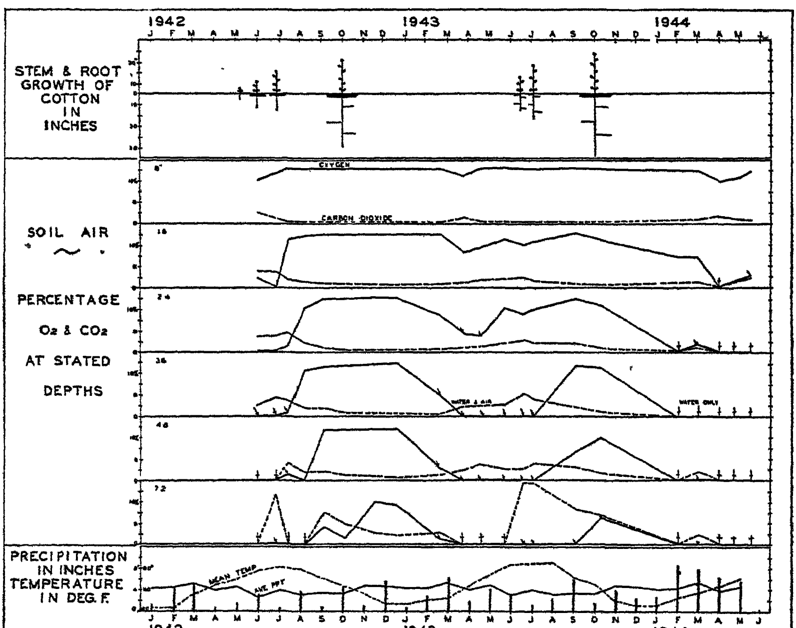

FIG. 4.—Relationship between the composition of the soil air and the growth and distribution of the roots (0–1 mm in diameter) of cotton under Houston clay, shallow phase.

fairly high level of oxygen at a depth of 16 inches at this time. About 80 to 90% of the small "feeder" roots (0–1 mm diameter) were in the top 6 inches of soil in the fall of the year.

Roots of mature cotton plants were very scarce below a depth of 4 feet, although occasionally some were traced to a depth of 60 inches. Poor aeration was probably always a factor limiting the root growth at this depth.

Excessively high carbon dioxide values occurred at the depth of 72 inches, directly above Selma Chalk. The percentages of oxygen at this depth were usually fairly low.

Very short tap roots were common on Houston clay, particularly on locations that remained poorly aerated and wet the longest (Fig. 5).

FIG. 5.—General morphology of cotton roots growing in Houston clay. The first three roots on the left show the influence of wet subsoils on the appearance of tap and branch roots of cotton. The root on the right developed on a drier location on the same series of plots.

In the location from which the data in Fig. 3 were obtained, as many as 60% of the plants had very short tap roots. In the location from which the data in Fig. 4 were obtained, usually fewer than 2 or 3% of the plants had short tap roots.

Sometimes seed lay in the ground without germinating until about July 1. Cotton from such seed, regardless of location, always produced normal tap roots.

Excessively large branch roots were typical of cotton developing on poorly aerated Houston clay (from cotton developing at the normal time). The large roots were predominately only 1 to 4 inches deep and ran more or less parallel with the contour of the soil between the beds. Eventually, the large roots turned downward.

Numerous small branch roots developed in soil that was somewhat dry.

Microscopical examination of cotton roots from Houston clay indicated that the roots were remarkably free from both fungi and nematodes.

AERATION AND ROOT GROWTH ON SARPY FINE SANDY LOAM

Sarpy fine sandy loam is an extremely variable alluvial soil. Air wells were established at different times during 1941, 1942, and 1943. Since different locations and soil treatments were involved in the different tests, the extremes in aeration of Sarpy sandy loam are probably indicated (Fig. 6).

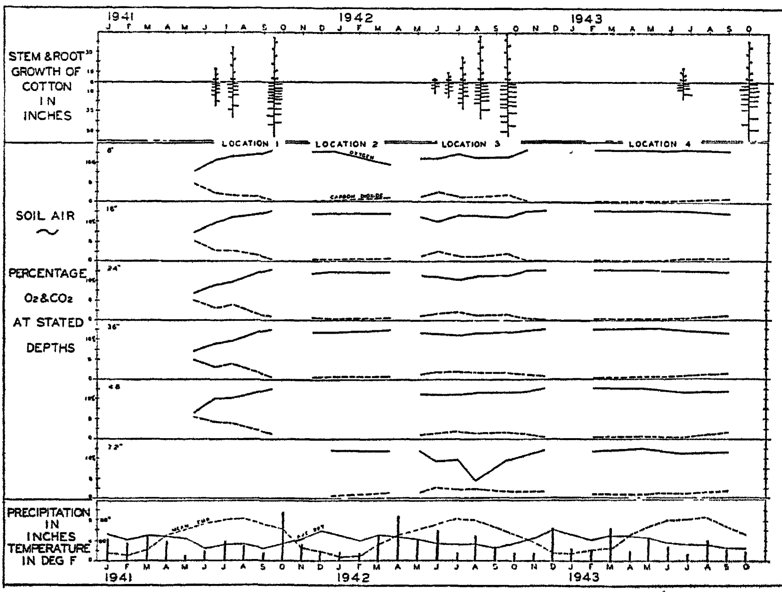

FIG. 6.—Relationship between the stem and root (0–1 mm in diameter) growth of cotton and the percentages of oxygen and carbon dioxide at different depths in Sarpy fine sandy loam.

The low oxygen and high carbon dioxide values obtained in the late spring of 1941 probably were a result of the decomposition of vetch. The cotton was not planted on beds in 1941 and this allowed the soil to collect more water and to remain wet longer than would have occurred had the land been bedded.

The percentages of oxygen were relatively high and the percentages of carbon dioxide were relatively low during the winter of 1941–42, and during the remainder of 1942 and 1943 at locations 2, 3, and 4. Cotton was planted on beds in both 1942 and 1943.

The tap and branch roots showed no indication of poor soil aeration (Fig. 7). About 70% of the tap roots were straight, 25% crooked, and 5% quite short. The crooked roots seemed to result from me-

chanical obstructions, such as stratified layers of soil or cotton stocks. The short tap roots resulted from the tips being killed by nematodes and root-rotting fungi. Vertically, the branch roots were distributed quite uniformly on the tap roots and did not grow parallel with the surface of the soil, as did those on Houston clay.

There was no evidence to indicate that root development was appreciably affected by poor aeration in this soil. An abundant development of roots deep in the soil indicated that the subsoil was not greatly inferior to the surface soil.

FIG. 7.—General morphology of cotton tap roots showing the distribution of branch roots on Sarpy fine sandy loam.

Cotton roots developing in Sarpy fine sandy loam were frequently attacked by both nematodes and fungi. The greatest injury to roots was found to occur in "sand pockets".

MECHANICAL COMPOSITION IN RELATION TO AERATION

The effect of mechanical composition of Sarpy soils at Scott, Miss., and at Stoneville, Miss., is shown in Fig. 8.

For comparison, the results are shown for one location under Houston clay. While a general relationship between the percentage of clay and soil aeration is evident, it is clear that other factors are also operative. The most important of these is the freedom with which water may escape downward through the soil. Under Houston clay, the downward movement of water is greatly restricted by the

underlying chalk. The Sarpy soils at Stoneville were underlain by sand, which improved the internal drainage considerably, even of the heavy clays.

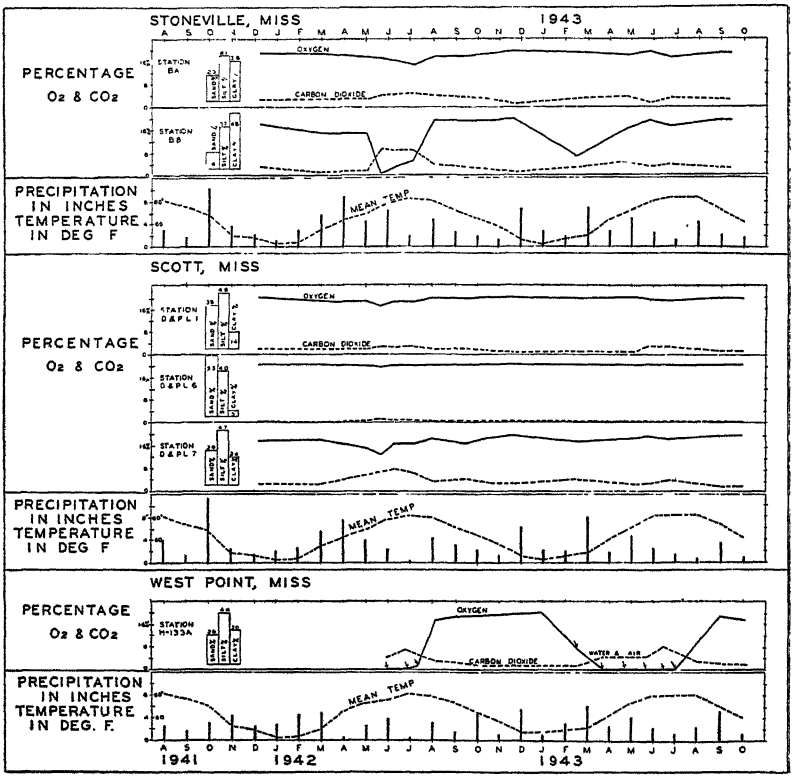

FIG. 8.—The influence of mechanical composition on soil aeration at three locations. Soils of the Sarpy series were studied at Stoneville and at Scott and of Houston clay at West Point. The depth of the wells was 36 inches.

ROOT STUDIES ON DIFFERENT SOILS COMPARED

Fig. 9 shows the general picture of root distribution under Houston clay having a wet subsoil, Houston clay having a moderately dry subsoil in the upper 18 to 24 inches, Sarpy fine sandy loam, and Ruston sandy loam at two stages of growth.

The results on Houston clay and on Sarpy fine sandy loam merely emphasize the data already presented on the influence of aeration on cotton root distribution. Some factor other than aeration seems to influence cotton root distribution under Houston clay. The evidence already presented seems to indicate that root growth in the subsoil is limited by the availability of phosphorus and nitrogen.

Ruston sandy loam is excellently aerated according to gas analyses studies already reported (14). Nevertheless, cotton roots develop more abundantly in surface than in subsoil, except in restricted

regions. In the subsoil cotton roots may develop very abundantly in places where old roots of the original forest have either rotted or burned. The subsoil of Ruston sandy loam is deficient in available phosphorus and nitrogen, with the above noted exceptions and is likely responsible for the pattern in which cotton roots are distributed. The results under Ruston sandy loam are presented to show the influence of an infertile subsoil, not complicated by poor aeration. The plot on which the cotton shown in Fig. 9 was grown had received no fertilizer for 12 years. Nematodes and root-rotting fungi attacked many of the cotton roots in Ruston sandy loam. Roots in the upper 12 inches were attacked to a far greater extent than deeper roots.

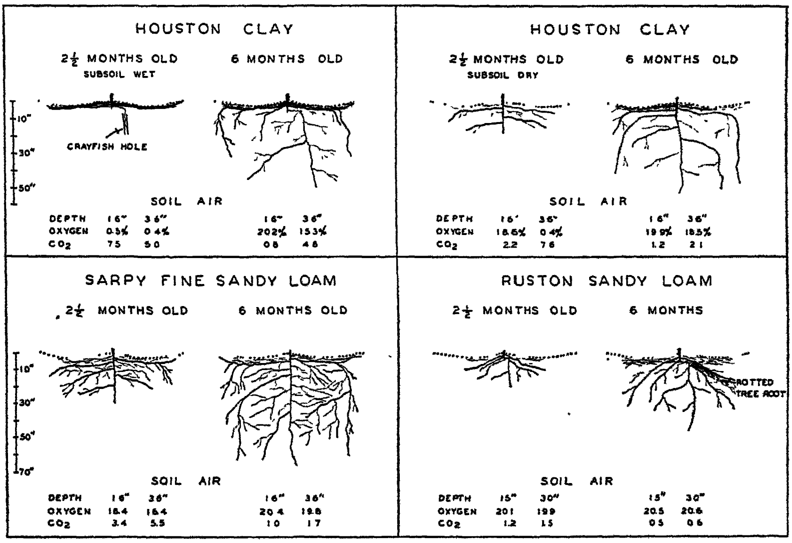

FIG. 9.—The distribution of cotton roots in Houston clay (poorly aerated site), Houston clay (moderately well aerated site), Sarpy fine sandy loam, and Ruston sandy loam at two stages of growth.

CONCLUSIONS

According to Kvarazkhelia (13), roots develop according to the law of limiting factors. Roots that developed in a location where one or more factors were below optimum tended to make the greatest growth in the region of the most favorable environment as regards moisture, fertility, temperature, oxygen, and porosity of soil.

Under Houston clay, differences in aeration during different years produced differences in cotton root distribution in late spring and early summer. Under conditions when the subsoil remained wet and poorly aerated, the bulk of the cotton roots remained in the upper 5 or 6 inches of soil; while under dry conditions, when the soil was better aerated, a good root development also occurred in the subsoil.

In the fall of the year, whether the year had been excessively wet or dry, the bulk of the cotton roots were in the upper 6 inches of

soil. Evidently some factor or combination of factors other than aeration were responsible for the distribution of roots on cotton plants in the fall of the year. Available phosphorus and nitrogen were quite deficient in the subsoil and evidently were factors affecting the distribution of roots.

Under Sarpy fine sandy loam, aeration and nutrition were usually sufficiently good and similar to the surface soil not to affect appreciably the distribution of cotton roots. These results do not mean, however, that aeration was optimum.

Houston clay was generally loose and seemingly well aggregated in the upper 4 to 6 inches, but compact below this depth. Under normal conditions, when the subsoil was high in moisture, virtually all of the roots were present in the top loose soil. The interrelation between aggregation, air capacity, soil moisture, and root growth were quite evident. Both Sarpy clay and Sarpy fine sandy loam were better aerated soils than was Houston clay. Any difference in aggregation between surface and subsoil was not sufficient to produce a difference in root development, such as occurred on Houston clay.

Houston soils are well known for the manner in which they crack when dry. These cracks may extend deep into the subsoil in the summertime and make possible for these soils occasionally to become well aerated to depths of 4 feet. A very great number of roots are broken by the process of cracking, but the beneficial effect of improving aeration may outweigh the root damage done. Schuster and Stephenson (18), Farnsworth (9), Boynton (4), and others have pointed out the importance of the larger pores on aeration. Farnsworth (9) found a good correlation to exist between noncapillary porosity and yields of sugar beets, when nutrition was ample. Schuster and Stephenson (18) found a relationship between the air capacity of the soil at different depths and the root distribution of nut trees.

The size of the soil particles influences the rate of gaseous diffusion in soils. In the present study, the influence of the mechanical composition of soil was demonstrated to affect the percentages of O_2 and CO_2. Boynton (4) and others have made similar observations. The relationship, however, is not absolute, since the arrangement of the various particles in the soil, the formation of aggregates, and the presence of noncapillary pores of one kind or another are also factors that influence diffusion.

Water is one of the most important factors influencing the aeration of soils. In the present work, rainfall brought about the most pronounced reduction in O_2 and increase in CO_2 on the soils containing the most clay. These results are the same as have been obtained by other workers. Wet subsoils had a marked influence on O_2 and CO_2 in Houston clay. The seasonal trends of O_2 and CO_2 in soils are undoubtedly influenced by the plants removing water from the soil by transpiration. Furr and Aldrich (10), in irrigation experiments, were able to demonstrate the interrelation between soil moisture and the percentage of O_2 and CO_2 in the soil air.

The roots of no plants appear to be able to grow into an oxygen-free medium. The effect of low soil O_2 and high water table on root development have been shown in the present paper. It has also been

shown that the high water table was associated with low soil O_2. Such results are well known. Elliott (8) found that the downward growth of corn roots stopped and turned laterally 18 inches above the water table on peat soils. Apparently insufficient oxygen was present for root growth for a distance of 18 inches above the water table. On Houston clay aeration also seemed to be poor for some distance above the water table, but the zone of poor aeration was certainly not so clearly defined as on the soil studied by Elliott. Howard and Howard (11), Bergman (2), and others have shown the effect of waterlogged conditions producing superficial root systems. Boynton (4) has pointed out that roots of trees are scarce in regions in the soil that are frequently low in O_2. The roots that appear in the poorly aerated soil likely developed there at the time of the year when such regions became well aerated.

The damaging influence of high CO_2 in the soil has been suggested frequently. Cotton root growth was not adversely affected by concentrations of 15% CO_2 and not seriously affected by concentrations of 30% CO_2, according to unpublished data by the author. It is only rare that CO_2 in soil is found to be above 12%; nevertheless, it is possible that local accumulations of carbon dioxide around roots may be sufficiently high to affect root growth.

Loehwing (15) and others have studied the influence of aerating soil on plants. He found that aerating soil produced plants having larger tops and roots. Aerating also increased the rate of nutrient absorption. Boicourt and Allen (3) grew roses in aerated and in unaerated soil. The aerated and unaerated soil contained 20.3 and 18.8% O_2 and 0.3 and 1.5% CO_2, respectively. In spite of the small differences as indicated by composition, the aerated plants grew 68.4 inches and the unaerated plants 37.3 inches in 3 months.

The role of diffusion is extremely important in soil aeration. Oxygen must diffuse from the larger soil pores to the smaller soil pores to the water films surrounding the roots and eventually to the interior of the roots themselves. Various O_2 gradients must be set up between the roots and the larger soil pores. It is the existence and nature of these diffusion gradients that determine the concentration of dissolved O_2 and CO_2 at any given point on the root surface. The combined effects of all of the various gradients will determine how satisfactorily a given soil is aerated at a given time.

Aeration data indicate certain oxygen relations existing within the soil. When oxygen values are close to 21%, aeration can be considered to be good, while values close to zero must be considered as being extremely poor and unsuited for root growth. Values between 1 and 20% oxygen can be evaluated only in a general way. Considerably more work will be necessary, and new methods must be developed before the aeration of soils in relation to root growth can be accurately determined.

SUMMARY

Studies are reported on the seasonal changes in soil aeration and cotton root growth under Houston clay and Sarpy fine sandy loam. Some studies are also reported on the influence of aeration under

Houston clay on oat root growth. Data are presented on the relationship between the depth of the water table and cotton root growth under Houston clay. The relationship between soil aeration and mechanical composition, pH, fertility (quick tests and pot experiments), and root distribution are presented and discussed.

The water table under Houston clay was generally between 2 and 3 feet deep until early summer. During 1940, the water table remained sufficiently high to prevent cotton roots from growing deeper than 8 inches until after August 1.

Low soil oxygen at the depth of 16 inches on Houston clay prevented all roots from growing deeper than this depth until after the soil had become better aerated.

Normally, cotton roots were predominately in the upper 0 to 6 inches until July or August. The above was related to the subsoil remaining fairly wet and low in oxygen. The soil became much higher in oxygen after the soil cracked and a rapid development of roots occurred in the subsoil.

On mature cotton in the fall of the year, 45% or more of the small "feeder" roots were in the upper 6 inches of soil under Houston clay. The moderately poor feeder root development in the subsoil under mature cotton is not wholly due to poor aeration but is due in part to other factors, probably a deficiency in available phosphorus and nitrogen.

The maximum depth cotton roots penetrated under Houston clay was usually 48 to 50 inches, although occasionally some roots grew to a depth of 60 inches.

In general, Houston clay in Mississippi can be considered to be poorly aerated from late fall until early summer, but the exact interval is dependent upon rainfall and the crops grown.

Sarpy fine sandy loam, seemingly, was sufficiently well aerated not to markedly affect root growth. The subsoil seemed to be fertile, with no element limiting root growth, with the possible exception of nitrogen. "Feeder" root distribution was very good in the subsoil. The maximum depth cotton roots usually penetrated was about 5 feet.

Ruston sandy loam was well aerated, but the subsoil was very deficient in nitrogen and available phosphorus. Under unfertilized cotton, root growth was predominately in the top 12 inches of soil, except in places where old tree roots had rotted.

A general relationship existed between the percentages of oxygen and carbon dioxide and the percentages of clay, although this relationship was greatly influenced by the permeability of the deeper layers of soil and chalk to water.

LITERATURE CITED

1. BALLS, W. L. The Cotton Plant in Egypt. London: Macmillan and Co. 1919.
2. BERGMAN, H. F. The relation of aeration to the growth and activity of roots and its influence on the ecesis of plants in swamps, Ann. Bot., 34:13–33. 1920.
3. BOICOURT, A. W., AND ALLEN, R. C. Effect of aeration on growth of hybrid tea roses. Amer. Soc. Hort. Sci. Proc., 39:423–425. 1941.

4. BOYNTON, D. Soils in relation to fruit growing in New York. Part XV. Seasonal and soil influences on oxygen and carbon dioxide levels of New York orchard soils. Cornell Univ. Agr. Exp. Sta. Bul. 763. 1941.
5. ———, AND REUTHER, W. A way of sampling soil gases in dense subsoils, and some of its advantages and limitations. Soil Sci. Soc. Amer. Proc., 3:37–42. 1938.
6. CANNON, W. A., AND FREE, E. E. Physiological features of roots, with especial reference to the relation of roots to aeration of the soil. Carnegie Inst. Wash. Pub. No. 368. 1925.
7. CLEMENTS, F. E. Aeration and air content. Carnegie Inst. Wash. Pub. No. 315. 1921.
8. ELLIOT, G. R. B. Relation between the downward penetration of corn roots and water level in peat soil. Ecology, 5:175–178. 1924.
9. FARNSWORTH, R. B. The effect of soil structure on sugar beet growth. Abs. Doctoral Dis. No. 35:167–183. 1941.
10. FURR, J. R., AND ALDRICH, W. W. Oxygen and carbon-dioxide changes in the soil atmosphere of irrigated date garden on calcareous very fine sandy loam soil. Amer. Soc. Hort. Sci. Proc., 42:46–52. 1943.
11. HOWARD, A., AND HOWARD, G. L. C. Some aspects of the indigo industry in Bihar. Part I. The wilt disease of indigo in Bihar. Part II. The factors underlying the seed production and growth of Java indigo in Bihar. Mem. Dept. Agr. India, Bot. Ser., 11:1–36. 1920.
12. JONES, T. N., HAMBLIN, I. E., AND LEONARD, O. A. Weed control and cotton tillage. Miss. Agr. Exp. Sta. Tech. Bul. 29. 1941.
13. KVARAZKHELIA, T. K. To the question of the biology of root systems of fruit trees. (summary in English) Abehas Agr. Exp. Sta. (Georgia U.S.S.R.), 105-113. 1927. (Cited from Yokum, W. W. Nebr. Agr Exp. Sta. Res. Bul. 95 1937).
14. LEONARD, O. A. Influence of sod and other factors upon the distribution of small tung roots in Ruston sandy loam. Amer. Soc. Hort. Sci. Proc., 42: 11–16. 1943.
15. LOEHWING, W. F. Physiological aspects of the effect of continuous soil aeration on plant growth. Plant Phys., 9:567–583. 1934.
16. MILES, I. E. Rapid testing of soils for plant food deficiencies under southern conditions. Soil Sci. Amer. Proc., 2:143–150. 1937.
17. ROMMEL, L. G. Luftvàxlingen i marken som ekologisk factor. Statens Skogsförsöksanst. (Swedish Inst. Expt. Forestry) Meddel., 19:125–359. 1922.
18. SCHUSTER, C. E., AND STEPHENSON, R. E. Soil moisture, root distribution and aeration as factors in nut production in Western Oregon. Ore. Agr. Exp. Sta. Bul. 372. 1940.

NOTES

THE USE OF MALE-STERILE IN BARLEY IMPROVEMENT

BARLEY breeders in America are very familiar with the composite hybrid mixtures sponsored by Harlan and Martini.[1] These mixtures are designed to provide genetic recombinations between desirable parent stocks with diverse ecological origins, and to foster the economical and selective advancement of the individual hybrids therefrom during segregation and genetic stabilization. It is now suggested that unrivaled possibilities for continuing recombinations, coincident with plant competition favoring the most vigorous plants, are afforded through use of a simple recessive male-sterile character. The male-sterile plants fail completely to set seed unless fertilized by foreign pollen. In heterozygous populations from 30 to 80% of their florets are cross-fertilized under California conditions.[2]

Jones's theory for the explanation of heterosis, as expanded by Powers,[3] postulates that a large number of dominant or partially dominant genes contribute toward its expression, either because of the direct role of favorable dominants or through multiplicative effects of mediocre or even unfavorable genes. The work of Immer,[4] indicates that the greater the manifestation of heterosis in a barley cross the greater the proportion of high-yielding isolates which can be recovered in later generations. In the California work with barley, maximum F_1 yields have been obtained from crosses involving two adapted varieties, although the largest percentage increases in yield above the means of two parents resulted from crossing two varieties from different ecological habitats.[5] To obtain maximum heterosis, large gene as well as plant populations with a facility for continuous recombination under competitive conditions seems very desirable.

For the practical utilization of the male-sterile character, two hybrid populations have been developed at Davis, Calif. One, designated as Composite Cross XIV (C. I. 7132), was produced by crossing each of the eight leading barley varieties in California on male-sterile, C. I. No. 5368-1, and compositing the F_1 seed. Male-sterile itself can be considered as a California adapted variety. The second, designated as Composite Cross XV (C. I. 7133), was derived by bulking F_1 plants from 625 randomly chosen pollen parents, all crossed on male-sterile. The pollen parents were drawn from the F_2 and F_3 generations of three Composite Cross populations (C. I. 6619, 6620, and 6725) which were derived from 33 varieties variously combined. Thus, the one population embodies great genetic and ecologic diversity, while the other stems from parents with a common adapta-

[1]HARLAN, H. V., and MARTINI, MARY L. A composite hybrid mixture. Jour. Amer. Soc. Agron., 21:487–490. 1929.

[2]RIDDLE, O. C., and SUNESON, C. A. Crossing studies with male-sterile barley. Jour. Amer. Soc. Agron., 36:62–65. 1944.

[3]POWERS, LEROY. An expansion of Jones's theory for the explanation of heterosis. Amer. Nat., 78:275–280. 1944.

[4]IMMER, F. R. Relation between yielding ability and homozygosis in barley crosses. Jour. Amer. Soc. Agron., 33:200–206. 1941.

[5]SUNESON, C. A., and RIDDLE, O. C. Hybrid vigor in barley Jour. Amer. Soc. Agron., 36:57–61. 1944.

tion and geographical origin. The immediate mean yield of Composite Cross XIV should exceed that for Composite Cross XV in California, and segregation will be restricted to fewer alleles. Composite Cross XV will give a much greater diversity of recombinations, however. Thus, in theory, the one population is intended to provide a means for substituting more favorable recombinations of genes in a fairly well-stabilized adaptation complex; the other, to provide new genes and new adaptation complexes. Both F_2 populations will be grown in isolation, at normal seeding rates, on 1/10-acre plots in 1945. Only male-sterile plants, naturally cross-pollinated, will be harvested, and the seed there from bulked. This will then be planted on 1/10-acre plots in 1946, and the selection procedure repeated. After about three seasons of continuous random natural crossing under competitive conditions, and when approximately half of the population has become homozygous male-sterile, it is proposed that the selection procedure be reversed, either by bulk or pedigree selection, to fix the normal fertility of the components, to increase homozygocity, and to begin their individual evaluation for yield and other qualities.

Admittedly, the course of the breeding procedure and all the likely problems associated therewith have not been fully charted. In giving this preliminary report, two objectives are sought. One is to emphasize for the benefit of both theoretical and practical breeders, the enlarged potentials afforded in barley breeding by male-sterile; the other, to offer available seed stocks to interested breeders.— COIT A. SUNESON, *Division of Cereal Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture, and the Department of Agronomy, University of California, Davis, Calif., cooperating.*

THE EFFECT OF VARIOUS FACTORS ON THE VALUE OF RYE FOR GREEN MANURE[1]

THE value of green manures in a soil management program is readily recognized. Rye is extensively used for this purpose. Although not a legume, it has certain advantages over a number of crops among which are wide climatic adaptability, low cost of seed, a less critical lime and fertilizer requirement than a legume, a rapid rate of growth, and resistance to winterkilling.

The prospect of low-cost nitrogen in the post-war period will tend to diminish the advantage of growing a legume rather than a non-legume for green manure purposes. A number of factors are associated with the value of a crop for green manure purposes. Among these factors are the yield of both tops and roots, stage of maturity of the crop, percentage of nitrogen in tops and roots, the effect of an application of chemical nitrogen on the growth and composition of the crop, the ability of the crop to absorb chemical nitrogen and thus prevent leaching of the nitrogen from the soil, and the effect of stage of maturity of the crop on the moisture content of the soil.

[1]Contribution from the Department of Agronomy, University of Delaware, Newark, Del. Published with the permission of the Director of the Agricultural Experiment Station.

FIG. 1.—Right to left, comparative heights of rye without and with a nitrogen top-dressing plowed April 13, April 28, and May 9.

Information on the above factors was obtained from a preliminary experiment considering the effect of a nitrogen top-dressing and the stage of maturity of rye on its value for green manure. A replicated, split-plot design experiment was located on a Sassafras loamy sand of low fertility at the Delaware Agricultural Experiment Substation, Georgetown, Del. A top-dressing of 50 pounds of nitrogen per acre in the form of ammonium nitrate (32.5% N) was applied March 27, 1944, on one-half of the rye plots. Plots were plowed at three different dates, April 13, April 28, and May 9. The respective height of the rye for these dates was, approximately, 12, 30, and 54 inches (Fig. 1). The 30-inch height represented the stage of growth just prior to heading and the 54-inch height, full head. U. S. 13 hybrid corn was planted May 11 and fertilized with 250 pounds per acre of 3–12–15 fertilizer. The results from the work are reported in Table 1.

Highly significant differences in the yield and percentage of nitrogen in both tops and roots were obtained on the basis of time of plowing and nitrogen top-dressing. However, there was very little difference in amount of nitrogen contained in the tops and roots with the second and third plowing dates. These data indicate that between the time that the rye plant is coming into head and reaches full head under conditions of the experiment, little nitrogen was absorbed from the soil and that the additional growth was associated with a decrease in nitrogen content of the plant tissue. Possibly with a larger application of nitrogen in the spring this result would have been modified.

Considerable attention has been given to the subject of the nitrogen content of plant material necessary to prevent immobilization of mineral soil nitrogen by microbial action. Data secured under laboratory conditions have shown, in general, that a nitrogen content of approximately 1.7% is necessary. However, this point has been questioned at various times and a figure of 1.2 to 1.3% has been suggested as more nearly approaching the requirement under actual field conditions. The behavior of the succeeding corn crop would

tend to bear out the latter view. Tissue tests made on the corn plants showed that in all cases where 50 pounds of nitrogen had been applied as a top-dressing, a high nitrate test was evident. Without the 50-pound application a blank nitrate test resulted. Extreme "firing" of the lower leaves of the corn, often improperly ascribed to dry weather, grown on the plots not top-dressed further substantiates the tissue test. It should be pointed out that the average nitrogen content for the rye top-dressed with nitrogen March 27 and plowed under May 9 was 1.38%. This is well below the 1.7 figure. At no time during the growing season did corn plants grown on these plots exhibit any symptoms of nitrogen shortage. It is possible, however, that part of the nitrogen applied as a top-dressing and not taken up by the plant would have slightly modified this observation.

TABLE 1.—*The effect of nitrogen and stage of maturity on the yield and nitrogen content of tops and roots of rye, 1944.**

Treatment		Percentage N		Pounds per acre					
				Yield			Nitrogen		
Pounds N	Date of plowing	Tops	Roots	Tops	Roots	Total	Tops	Roots	Total
0	Apr. 13	2.02	0.97	449	208	657	9.1	2.0	11.1
50	Apr. 13	4.89	1.90	543	204	747	26.6	3.9	30.5
0	Apr. 28	1.51	0.51	854	325	1,179	12.9	1.7	14.6
50	Apr. 28	2.58	1.29	1,667	505	2,172	43.0	6.5	49.5
0	May 9	0.95	0.40	1,619	341	1,960	15.4	1.4	16.8
50	May 9	1.55	0.53	2,871	552	3,423	44.5	2.9	47.4

*All yield data expressed on oven-dry weight basis. Differences in yield and percentage of nitrogen in tops and roots between dates of plowing and application of nitrogen are well above the 1% level. The author is indebted to Mr. C. W. Woodmansee, Assistant Chemist of the Delaware Agricultural Experiment Station for analyzing the samples for nitrogen.

The rye crop was able to account for between 60 and 70% of the added nitrogen in its tissue one month after its application.

The data further show the fallacy of attempting to maintain soil organic matter if the rye is severely pastured before plowing under. Results from the average of the three plowing dates indicate that 8.2 times as much nitrogen and 3.7 times as much organic matter are contained in the tops as in the roots of the plant. If a large percentage of the top is removed by pasturing, very little organic matter will be returned to the soil and very little favorable effect on the growth of the following crop can be expected.

Although corn yields were higher on plots that had received the nitrogen top-dressing, the yields were far below normal, 8 to 12 bushels of nubbins per acre. Extremely dry weather throughout the growing season was responsible for this situation. Approximately 0.7 inch of rainfall was recorded during the month of July. Due to the lack of soil moisture, the addition of the nitrogen as a top-dressing was not favorably reflected in practical yield increases.

The effect of late plowing of a green manure crop on the moisture content of the soil is important. The respective soil moisture contents

for the April 28 and May 9 dates for the plots top-dressed with nitrogen was 7.8% and 5.8%, representing a 25.6% decrease in soil moisture between the two dates or a dissipation of 20 tons of water by the rye crop during this period. The effect of this decrease in moisture supply was evidenced in the uneven and retarded growth of the corn plants on these plots.—JOHN F. DAVIS, *Delaware Agricultural Experiment Station, Newark, Del.*

BOOK REVIEWS

THOMAS JEFFERSON AND THE SCIENTIFIC TRENDS OF HIS TIME

By Charles A. Browne. Waltham, Mass.: Chronica Botanica. Vol. 8, No. 3, pages 361–424. illus. 1944. $1.25.

A USEFUL evaluation of the scientic influence of such a figure as Thomas Jefferson could only be made by a man of broad scholarship in both history and science. Dr. Browne has these qualifications; and he has taken the pains to do a job that is both thorough and interesting.

The author has abstracted the essentials from a vast literature to give a clear picture of Jefferson's concepts in the various fields of science, of his views regarding the social significance of science, and of the influence he had in the development of scientific research and thought. Despite the obvious marks of careful scholarship, the text is smoothly written and interesting. Many relavent quotations are given from Jefferson's letters and papers, together with illustrations and maps from the books he wrote and from those he read.

Botany, chemistry, geology, geography—these and other sciences were all of great interest to Jefferson; but he gave special attention to their practical application in agriculture, industry, and the household arts. Yet the instructions that he gave to Lewis for conducting the famous Lewis and Clark Expedition show clearly enough his appreciation for the need of fundamental research as the basis for progress in the applied sciences.

The author draws easily on his wide knowledge of the history of science to give the reader a clear picture of Jefferson's views in relation to those of the distinguished scientists and agriculturists of his time. In fact, he accomplishes the double task of evaluating the period as well as the rôle Jefferson played in it.

Any reader interested in science, in agriculture, in Jefferson, or in the formative period of the United States will certainly find this little book of great interest. (And it is also recommended for just good, quiet reading without any purpose at all.)—CHARLES E. KELLOGG.

INVESTIGACIONES AGRONÓMICAS

By Alberto Boerger. Montevideo, Uruguay: Casa A. Barreiro y Ramos S. A. 3 Vols. 2,250 pages, 1943. (In Spanish).

THE author is the distinguished Director of the no less distinguished Uruguayan Institute "La Estanzuela" located near Montevideo, where for years he has guided the scientific work in

agriculture for the country in the fields which touch solely on the plant sciences, which, as in Argentina, are related to animal industry on account of the development of cattle ranges, permanent pastures, and specialized cereal production.

In his preface, the author points out that the work is essentially a compilation of material, well documented so that the critical may seek out the sources, and addressed particularly to professional agricultural workers in South America. He notes, moreover, that the work is in a way an outgrowth of his earlier work "Observaciones sobre Agricultura" which was less of a resumé of the field and more personal in its orientation.

Each volume is planned to stand alone and yet to be subject to the common theme, "*la produccion vegetal al servicio del hombre*" which might be glibly reduced to "Crops for Man". The first volume, The Bases of Crop Production, deals with a philosophy of agriculture, natural resources of the soil, observations on climate, agricultural production, cultural practices, use of fertilizers, and factors which disturb production. The topics listed are not exact translations of the titles used, but free paraphrases of the titles.

Volume II, which deals with genetic studies and the application of its principles to the great River Plate area, includes heredity, variation, and selection; outline of the field for use of these factors and practices; outline of the government organization in the area (Uruguay, Argentina, and the southern part of Brazil); longer sections on cereal, forage, and oil-producing crops, as well as others plants "of considerable cultivation".

Volume III, "Production and Man", deals with economic and social aspects of agricultural production and, while no less interesting than the other volumes, leaves one in a much more controversial field. The section heads are production and consumption, commercialization, progress and want, a panorama of the hour, and the latest perspective. This volume also contains the valuable appendices; bibliography of the Station "La Estanzuela"; analytic index of the former work "Observations on Agriculture"; index of authors, institutions, etc., cited in the present work; index of scientific names; and general index.

After each chapter there is a resumé and a special bibliographic list for that chapter. One is impressed at the breadth of the reading of the author but even in the too hurried reading that has preceded this reviewing, one finds himself returning to that interesting section in Volume I, "The Personal Factor" which touches all the enunciations of problems, the orientation of work, the understanding of the relation of the whole work to the national or larger situation, and so on. And so reading, one wishes that the author had betrayed himself more explicitly in his present work.—B. Y. MORRISON.

AGRONOMIC AFFAIRS

STANDING COMMITTEES OF THE AMERICAN SOCIETY OF AGRONOMY FOR 1945

FERTILIZERS

R. W. Cummings, *General Chairman*

SUBCOMMITTEE ON FERTILIZER APPLICATION

J. A. Chucka, *Chairman*
F. E. Bear
F. E. Boyd
E. R. Collins
H. J. Harper
S. B. Haskell
M. S. Hazen
W. T. McGeorge
J. E. McMurtrey
C. E. Millar
R. M. Salter
G. D. Scarseth
H. R. Smalley
S. C. Vandecaveye
C. W. Whittaker
R. E. Yoder

SUBCOMMITTEE ON DIAGNOSIS OF PLANT NUTRIENT STATUS

G. D. Scarseth, *Chairman*
R. H. Bray
R. L. Carolus
H. D. Chapman
J. A. Chucka
O. W. Davidson
J. B. Hester
G. N. Hoffer
M. F. Morgan
Michael Peech
J. R. Piland
C. B. Sayre
G. W. Volk

SUBCOMMITTEE ON FERTILIZER RATIOS

C. E. Millar, *Chairman*
R. V. Allison
R. P. Bartholomew
F. C. Bauer
Richard Bradfield
J. A. Chucka
R. W. Cummings
T. B. Hutcheson
M. H. Lockwood
D. D. Long
H. B. Mann
R. P. Thomas
S. C. Vandecaveye
N. J. Volk
R. E. Yoder
H. H. Zimmerley

SUBCOMMITTEE ON NITROGEN UTILIZATION

F. E. Bear, *Chairman*
O. S. Aamodt
R. W. Cummings
W. H. Pierre
S. C. Vandecaveye
N. J. Volk

ADVISORY COMMITTEE TO WAR FOOD ADMINISTRATION

R. W. Cummings, *Chairman*
Richard Bradfield
Clarence Dorman
R. E. Yoder

SOIL TILTH

B. T. Shaw, *General Chairman*

FOR AMERICAN SOCIETY OF AGRONOMY

B. T. Shaw, *Chairman*
T. M. McCalla
L. D. Baver
E. N. Fergus
M. B. Russell

FOR AMERICAN SOCIETY OF AGRICULTURAL ENGINEERS

L. F. Reed, *Chairman*
M. L. Nichols
E. G. McKibben
A. P. Yerkes
J. H. Neal

WAR AND POST-WAR ADJUSTMENTS

R. D. Lewis, *Chairman*
M. F. Miller
Norman P. Neal

EXTENSION PARTICIPATION

D. L. Gross, *Chairman*
C. F. Simmons
O. S. Fisher
Earl Jones
H. E. Hendricks
R. L. Matlock
I. P. Trotter
E. L. Worthen

BIBLIOGRAPHY OF FIELD EXPERIMENTS

H. M. Steece, *Chairman*
F. R. Immer
H. M. Tysdal

STUDENT SECTIONS

H. K. Wilson, *Chairman*
W. O. Collins
R. L. Cushing
G. H. Dungan
J. B. Peterson
J. A. Rigney
J. W. Zahnley

PASTURE IMPROVEMENT

O. S. Aamodt, *Chairman*
H. L. Ahlgren
B. A. Brown
D. R. Dodd
C. R. Enlow
C. M. Harrison
Robert Lush
O. McConkey
George Steward
J. D. Warner

MONOGRAPHS

Charles E. Kellogg, *General Chairman*

For Crops:
H. H. Laude, *Chairman*
E. N. Fergus
S. C. Salmon

For Soils:
W. H. Pierre, *Chairman*
O. C. Magistad
R. M. Salter

HISTORIAN

R. I. Throckmorton

RESOLUTIONS

Ide P. Trotter, *Chairman*
B. B. Bayles
R. W. Cummings
R. I. Throckmorton
J. D. Luckett, *Ex-officio*

EDITORIAL BOARD

J. D. Luckett, *Editor*

R. J. Garber,
Associate Editor in Crops

Emil Truog
Associate Editor in Soils

L. F. Graber
H. K. Hayes
M. T. Jenkins
R. D. Lewis
Ide P. Trotter
Consulting Crops Editors

I. L. Baldwin
L. D. Baver
G. B. Bodman
Richard Bradfield
W. H. Pierre
Consulting Soils Editors

F. R. Immer
Consulting Editor in Statistics

SELECTION OF FELLOWS

H. D. Hughes, *Chairman*
O. S. Aamodt
F. E. Bear

COOPERATION WITH FOREIGN SCIENTISTS

Richard Bradfield, *Chairman*
C. E. Kellogg
H. K. Hayes
O. S. Aamodt

CROPS SECTION COMMITTEES FOR 1945

VARIETAL STANDARDIZATION AND REGISTRATION

M. A. McCall, *Chairman*
A. C. Arny
H. B. Brown
J. Allen Clark
F. N. Briggs
L. F. Graber
H. K. Hayes
E. A. Hollowell
R. E. Karper
W. J. Morse
T. R. Stanton
T. M. Stevenson
G. H. Stringfield

NOMENCLATURE OF GENETIC FACTORS IN WHEAT

E. R. Ausemus, *Chairman*
F. N. Briggs
J. P. Harrington
L. P. Reitz
W. W. Worzella

METHODS OF SEED PRODUCTION AND UTILIZATION OF IMPROVED STRAINS OF FORAGE CROPS

R. D. Lewis, *Chairman*
O. S. Aamodt
H. R. Albrecht
A. L. Clapp
O. S. Fisher
E. F. Frolik
L. F. Graber
F. V. Grau
E. A. Hollowell
R. D. Mercer
H. C. Rather
H. A. Schoth
H. M. Tysdal
R. G. Wiggans
J. C. Hackelman

CROP TERMINOLOGY

C. J. Willard, *Chairman*
K. S. Quisenberry
C. P. Wilsie

JOURNAL

OF THE

American Society of Agronomy

VOL. 37 FEBRUARY, 1945 NO. 2

EXCRETION OF NITROGEN COMPOUNDS BY SOME LEGUMES GROWN IN SAND CULTURE[1]

HUGH G. MYERS[2]

CONSIDERABLE work was done on excretion of nitrogen compounds from legume roots prior to the extensive studies of Virtanen (5)[3] and associates of the Biochemical Institute, Helsinki, Finland. Excretion of these nitrogen compounds occurs erratically and some of the early work probably was not published because replications did not agree within the limits thought necessary for scientific standards of reproducibility. Principal credit for establishing proof and bringing about general acceptance of the excretion of nitrogen compounds from legume roots, however, goes to the Finnish workers. The Helsinki findings have not been widely confirmed, but this is understandable because the factors governing the process are complex, not fully known, and may vary at different geographic locations and under different environmental conditions.

Comprehensive reviews by Wilson (7) and by Burk and Burris (2) and the discussion by Wyss and Wilson (9) make further reference to the literature unnecessary.

The object of the work reported in this paper was to demonstrate nitrogen excretion and endeavor to learn more with regard to the conditions controlling the phenomenon. Such knowledge is fundamental to adequate study of the excreted nitrogen compounds and of the mechanism of the process. The biochemical study of fixed excretion intermediates already has contributed materially to our knowledge of symbiotic nitrogen fixation (6).

MATERIALS AND METHODS

Because of the erratic occurrence of nitrogen excretion and present lack of exact knowledge of the conditions bringing it about, it appears desirable to give

[1]The investigation reported in this paper is in connection with a project of the Kentucky Agricultural Experiment Station and is published by permission of the Director. Received for publication August 28, 1944.

[2]Formerly Assistant in Agronomy, Kentucky Agricultural Experiment Station, Lexington, Ky., later Associate Professor of Soils, Kansas State College of Agriculture and Applied Science, Manhattan, Kans.; now in the armed services.

The writer wishes to acknowledge the helpful suggestions of Prof. P. E. Karraker, University of Kentucky, under whose general direction this study was made.

[3]Figures in parenthesis refer to "Literature Cited", p. 89.

in some detail the procedures used in these experiments. Much of this information and summaries of the results of the experiments are given in Tables 1 and 2.

Grasses and mixtures of grasses and legumes were grown in white quartz sand, using a nitrogen-free nutrient solution. The transfer of nitrogen from the legume to the grass as determined by observing relative growth of the associated grass and the grass grown alone, and also by the final nitrogen content of the associated and nonassociated grass, was the criterion of nitrogen excretion.

Plants were started in the jars either from seeds or from transplants. Large seed, as vetch and rye, were screened to obtain uniform size. The seed and seedlings were disinfected with 1-1000 $HgCl_2$ in dilute HCl followed by five rinsings with distilled water. Seedlings were wholly immersed in the disinfectant. In transplanting the seedlings, the remaining portion of the seed was removed, except in the first experiment where only the seedcoat was removed.

The seeds were germinated in extra portions of the sand or between filter paper in Petri dishes. Use of seedlings had several advantages over direct seeding, *viz.*, (a) there were no ungerminated legume seeds to serve as a source of nitrogen to the nonlegume plants upon decay; (b) the greater portion of the seed could be removed from the seedling before transplanting, reducing this source of nitrogen to the grass from an average of 1.4 to 0.6 mgm; (c) removing the energy material in the seed reduced the possibility of nonsymbiotic nitrogen fixation; (d) use of seedlings gave quicker growth and earlier fixation.

Other usual precautions were observed to prevent contamination; however, Cholodny slides placed in some of the containers showed considerable activity both as to number and variety of organisms. The fact that additions of fresh soil to some did not result in benefit to the grass in the mixture associations indicates that legume root decomposition was probably not a complicating factor in these experiments.

Legume plants were inoculated with several-day-old *Rhizobium* slants by adding distilled water to the tubes, shaking, diluting, and adding a few cc to each container. Also, the roots of seedlings were dipped in water suspension of the proper organism prior to setting. Uninoculated controls grew very little. Inoculated legumes at the time of harvest were well nodulated. Fixation of as much as 20 mgm of nitrogen per legume plant frequently occurred. The quantity fixed was as low as 1 mgm per legume plant in the treatments having lowest potassium content.

Hiltner's nitrogen-free nutrient solution as reported by Virtanen and Laine (6), after being modified, was used as the nutrient source. Minor elements were added, ferric tartrate was substituted for ferric chloride, and in some experiments additional quantities of the ferric and tricalcium phosphate were mixed dry with the sand. Comparisons of the nutrient sources showed little difference as to their effect on plant growth.

A small quantity of $Ca(NO_3)_2$ was added to each container at the beginning of the experiment to hasten growth and initiation of nitrogen fixation by the legumes. This was added at a rate to supply 0.10 mgm nitrogen per plant in experiments 1, 2, 3, and 4; 0.25 mgm in experiment 5, and part of experiment 6; and 0.50 mgm in the rest of experiment 6, *viz.*, jars 33-50.

Plants were watered with distilled water every 5 to 7 days when small and every 2 to 4 days afterwards. Water was added up to 25% of the dry sand weight except that in experiment 6, 22.5% was the maximum.

EXPERIMENTAL RESULTS AND DISCUSSION

SIMPLE TESTS FOR OCCURRENCE

The first and third experiments were made without special treatments to find out if excretion would occur. In experiment 1, in addition to the plant combinations shown in Table 1, associations of Dutch white clover, *Trifolium repens*, with Kentucky bluegrass, *Poa pratensis*, and Korean lespedeza, *Lespedeza stipulacea*, with orchard grass, *Dactylis glomerata*, were started. These legumes grew poorly under the conditions of the experiment and no further work was done with them. In each of the other experiments some treatments

were similar to those in the first and third experiments. Conditions were considered favorable for 46 associated growths. In two of these, both in experiment 1, there was evidence of benefit to the associated nonlegume. The rye of these vetch-rye associations in experiment 1 contained 5 and 3 mgm more nitrogen, respectively, than the rye grown alone. This increased nitrogen content is thought to have been due to the occurrence of nitrogen excretion. Unfortunately, the containers had been used in previous experiments and some evidence of nitrogen carry over by similar containers occurred in experiment 3; therefore, the evidence for excretion is inconclusive.

EFFECT OF VARYING THE POTASSIUM SUPPLY

Wilson and Wyss (8) and Bond and Boyes (1) have advanced similar hypotheses to account for the occurrence of nitrogen excretion, which are, essentially, that nitrogen excretion occurs only when a delicate physiological balance is maintained in the legume whereby carbohydrate synthesis by the plant and attendant nitrogen fixation in the nodule exceed the rate of assimilation of the fixed nitrogen compounds by the plant. The excess nitrogenous compounds then diffuse through the cell wall. These workers attempted to obtain this special physiological condition by varying growth factors other than nutrient supply. Experiments 2 and 4 of the work reported in this paper had a similar purpose, except that attempts were made to obtain this special physiological balance by varying potassium supply. Potassium was chosen because of its generally accepted role in carbohydrate translocation.

In experiments 2 and 4 treatments were included with initial concentrations of 0.50, 0.10, 0.08, 0.06, 0.04, and 0.02 gram KCl per liter, except that the 0.50-gram per liter concentration was omitted from experiment 4. Further details of the two experiments are given in Table 1.

In these experiments there was a fairly uniform gradation from small growth at the 0.02-gram per liter concentration to good growth at the 0.25-gram per liter treatment. The 0.50-gram KCl per liter concentration was detrimental to growth in experiment 2.

Nitrogen excretion probably occurred in one instance in experiment 2. This was in one of the two treatments of 0.06 KCl per liter. A short period of rapid growth with greening was observed in the rye prior to the appearance of potassium deficiency symptoms and at about the time nitrogen fixation became apparent. Nitrogen analyses of the rye plants in this experiment substantiated this observation. The associated rye plants in this jar contained 1.4 mgm more nitrogen than the corresponding nonassociated rye plants. This difference is small but appears to be significant because of the very close agreement in nitrogen content of the rye plants in the other respective pairs of jars in the experiment. As an average of these other pairs, the associated rye plants contained only 0.01 mgm more nitrogen than the corresponding nonassociated plants. The range in individual pairs was from 0.32 mgm less to 0.27 mgm more.

TABLE 1.—*Summary of the conditions*

Experiment	No. 1		No. 2				No. 3
Plants associated*	Hairy vetch, Balbo rye	Hairy vetch, Italian ryegrass	Red clover, orchard grass	Alfalfa, bromegrass	Hairy vetch, Balbo rye	Hairy vetch, Balbo rye	Hairy vetch, Balbo rye
Starting date	Vetch on July 17, 1940; July 29, 1940; Aug. 5, 1940		Sept. 16, 1940	Sept 24, 1940	Oct. 5, 1940	Oct. 18, 1940	Nov. 2, 1940
Harvest date	Sept. 12, 1940		Dec. 23, 1940				Feb. 15, 1941
Rhizobia‡	W. 311		W. 209	W. 100	W. 311	W. 311	W. 311
Container	Used ½-gal glazed jars		Pint glass jars wrapped in heavy paper				Used ½- and 1-gal. glazed jars, same as Exp. 1
No. of legume (L) and nonlegume (NL) plants per container	4 L and 8 NL or 12 NL		2 L and 4 NL or 6 NL				6L and 12 NL or 18 NL
Day length	Similar to natural day length at this latitude						
Temperature, °F	68°–93° most of the time		45°–80° most of the time				
Where plants were grown	Whitewashed greenhouse		Exceptionally well lighted laboratory having NE, SE, and SW exposures				Greenhouse
No. of containers with mixed growth	3	3	10	10	10	10	7
Special treatment			Different concentrations of KCl; development of K deficiency and alleviation by KCl addition; vitamin B_1 application; addition of sterile and unsterile soil				
Type of legume growth	Excellent	Excellent	Good until limited by K-deficiency				Fair
Excretion and remarks	2 cases of benefit to rye	No excretion	No excretion	No excretion	One case of benefit to rye	No excretion	No excretion
			Associated rye plants in jars receiving soil additions were not benefitted				

*Scientific names in order are: *Vicia villoso, Secale cereal, Lolium multiflorum, Trifolium prate*

‡See Table 2 for further details.

and results of all experiments.

No. 4				No. 5	No. 6†
Hairy vetch, Balbo rye	Hairy vetch, Balbo rye	Red clover, orchard grass	Alfalfa, brome-grass	Hairy vetch, Balbo rye	Hairy vetch, Balbo rye
Mar. 6, 1941	Mar. 17, 1941	Mar. 17, 1941	Mar. 22, 1941	Seeding Nov. 27, 1941 Transplant Dec. 5, 1941	Jan. 30, 1942
Aug. 4, 1941	Aug. 5, 1941	Aug. 21, 1941	Aug. 21, 1941	Feb. 8, 1942	Apr. 9, 1942
W. 311	W. 311	W. 209	W. 100	W. 311, HX and Urbana commercial	W. 311
Pints as in Exp. 2				Pints as in Exp. 2 and new ½-gal. glazed jars Pints same as in Exp. 2 and 4; ½-gal. same as in Exp. 1	New ½-gal. glazed jars
Same as in Exp. 2					3 L and 6 NL or 6 NL
				Normal; normal + 5 hrs.	9, 12, 15 and 22 hrs.
					50°, 55°, 60° and 65°
Greenhouse whitewashed, Apr. 19, 1941				Greenhouse	Air-conditioned tobacco-curing chambers
10	10	10	10	40	24
Similar to Exp. 2 except no vitamin B_1 used; also the greenhouse was whitewashed during the experiment, giving a shading effect				Direct seeding compared with transplanting; artificial light supplement; strain of organism; type of container; addition of sterile and unsterile soil	Variable temperature, humidity, and day length
Fair	Fair	Good	Good	Poor to excellent; transplanted better than seeded; long day best	Poor to excellent
Until limited by K-deficiency					
No excretion. Experiment continued until nonlegumes benefitted from root decomposition; this did not occur until near death of the legume				No benefit to rye; associated rye in the jars receiving soil additions were not benefitted	3 cases benefit to rye

nse, Dactylis glomerata, medicago sativa, and *Bromus inermis.*

After all plants receiving less than 0.10 gram KCl per liter in the nutrient solution exhibited potassium deficiency, 0.02 gram KCl per liter of solution was added to the containers in the experiment. There was some resumption of growth and nitrogen fixation by the legumes, but no further evidence of nitrogen excretion. There was no indication of nitrogen excretion in experiment 4. This experiment was conducted similarly to experiment 2, except that it was located in a greenhouse and 0.08 gram KCl per liter was added to alleviate K deficiency.

Failure in these two experiments to induce nitrogen excretion by varying the potassium supply agrees with results published by Ludwig and Allison (3) on the effect of insufficient potassium on nitrogen excretion by peas. These workers also limited the supply of phosphorus and in one instance of sulfur without causing nitrogen excretion.

AN EXPERIMENT IN A CONTROLLED ENVIRONMENT

Six chambers, each approximately 4 × 4 × 4 feet and designed for studies in curing burley tobacco (4), were used for growing the plants in the sixth experiment. Temperature, humidity, and day length were closely controlled. Each chamber was equipped with a 500-watt clear bulb and a large white reflector for illumination. Light intensity was adjusted to 550 foot candles at the surface of the sand. The conditions in the chambers during the experiment were maintained very close to the plans as shown in Tables 1 and 2.

The 50° temperature resulted in poor growth. Before the temperature was raised, the 12-hour-day plants in this group were better than the plants grown with 9- or 15-hour day lengths. Day length had a more marked influence on the vetch grown at 65°. Growth was most vigorous and evidence of nitrogen fixation appeared earliest in the 15-hour chamber, with the 9-hour treatment second in this respect. The vetch with the 12-hour day was practically as good as the 9-hour treatment after six weeks but both were inferior to the 15-hour treatment.

Excretion may have occurred in three jars, Nos. 58, 61, and 2. (See Table 2 for the experimental conditions). Rapid rye growth with disappearance of nitrogen-deficiency symptoms was observed in jars 58 and 61 at the end of the fifth week. Differences had not been obvious in jar 2 by the time the jars were changed at the end of 6 weeks. Observations were difficult to make after this because of tangled growth. The rye plants in these jars contained 1.4 to 2.5 mgm more nitrogen, respectively, than the corresponding rye plants grown alone.

Two of the three cases of benefit to the rye in this experiment occurred where temperature and daylight were maintained at 65° F and 12 hours, respectively, throughout the experiment. The growth of the legumes in these jars was fairly good. Wyss and Wilson (9) have observed that excretion usually occurs at intermediate growth rates.

TABLE 2.—*Conditions and results of experiment 6.*

Jar No.	Plants*	Experimental conditions†				Nitrogen content of the 6 rye plants in mgms	Jar No.	Plants	Experimental conditions				Nitrogen content of the 6 rye plants in mgms
		Jan. 31–Mar. 16‡		Mar. 16–Apr. 9					Jan. 31–Mar. 16		Mar. 16–Apr. 9		
		Temperature, °F	Day length in hours	Temperture, °F	Day length in hours				Temperture, °F	Day length in hours	Temperture, °F	Day length in hours	
33	R–V	50°	9	60°	9	6.65	51	R–V	65°	9	65°	22	4.15
34	R–V	50°	9	65°	9	5.85	52	R–V	65°	9	65°	15	4.70
35	R	50°	9	60°	9	4.85	53	R	65°	9	60°	9	5.10
36	R–V	50°	9	65°	12	6.40	54	R–V	65°	9	65°	9	4.00
37	R–V	50°	9	55°	15	6.65	55	R–V	65°	9	60°	9	4.95
38	R	50°	9	65°	9	5.40	56	R	65°	9	65°	9	4.55
39	R–V	50°	12	65°	15	5.70	57	R–V	65°	12	60°	9	4.50
40	R–V	50°	12	65°	22	6.75	58§	R–V	65°	12	65°	12	6.40
41	R	50°	12	65°	22	4.85	59	R	65°	12	65°	12	5.00
42	R–V	50°	12	65°	9	6.15	60	R–V	65°	12	65°	22	4.50
43	R–V	50°	12	65°	12	6.45	61§	R–V	65°	12	65°	12	7.00
44	R	50°	12	65°	12	5.00	62	R	65°	12	65°	22	4.70
45	R–V	50°	15	55°	15	5.15	63	R–V	65°	15	65°	15	5.65
46	R–V	50°	15	65°	15	5.55	64	R–V	65°	15	65°	9	4.80
47	R	50°	15	65°	15	4.65	9	R	65°	15	65°	15	4.65
48	R–V	50°	15	60°	9	5.40	1	R–V	65°	15	65°	22	5.70
49	R–V	50°	15	55°	15	5.90	2§	R–V	65°	15	55°	15	7.15
50	R	50°	15	55°	15	5.15	3	R	65°	15	55°	15	4.65

*R = 6 rye plants; R-V = 6 rye plants and 3 vetch plants.
†Relative humidity was 70% from Jan. 31 to Feb. 22 and 60% from Feb. 22 to Apr. 9.
‡All 50° temperatures changed to 55° on Feb. 16.
§Excretion may have occurred.

EFFECT OF ADDING SMALL QUANTITIES OF SOIL

Little is known of the possible transfer of fixed nitrogen present in legume roots and nodules to an associated grass by root decomposition during active growth stages of the legume.

It was possible in these experiments to obtain some indication of this transfer in sand cultures and at the same time test the possibility of chance introduction of microorganisms into mixed growth containers being responsible for the occasional benefit to the grass.

Treatments were included in experiments 2, 4, and 5 in which small quantities of fresh field soil were added to some jars and quantities of the same soil after sterilization to other jars. In experiments 2 and 4; 0.1-gram portions of a mixture of surface soil from several places on the Station farm were added to the surface of the jars and washed into the sand with water. In experiment 5, 1- and 2-gram portions of surface soil from four tobacco rotation plots using vetch as a cover crop were added to half-gallon and gallon jars, respectively.

In experiment 4, 16 containers received the soil at the beginning of the experiment. In addition, 48 more containers received soil when they had served their purpose in the test of varying the potassium supply. A total of 88 associations in the three experiments received the soil additions. Sterile soil was used in 32 of these instances and unsterile soil in 56.

As long as the legumes made good growth, the soil additions were not observed to bring about transfer of nitrogen to the associated nonlegume. It was not until the legumes definitely began to die that the associated nonlegume benefited. It would appear that root decomposition of growing legumes is not usually a complicating factor in studying nitrogen excretion in sand cultures.

TESTS OF SEVERAL OTHER FACTORS

Several other differences in procedure or growth conditions were tried in some of the associations in experiments 2, 4, and 5 with no effect on nitrogen excretion.

In experiment 2, several jars received additions of a commercial vitamin B_1 preparation. This sharply reduced red clover growth, slightly reduced vetch growth, and had no effect on alfalfa growth. Shading has been used to induce nitrogen excretion (8). Partial shading resulted from whitewashing the greenhouse in experiments 1 and 4 (Table 1). Two-day lengths were tested in experiment 5. One-half of the treatments received the natural daylight, while the other half received an additional 4¾ hours of artificial light in the evening. Plants grew faster with the additional lighting.

Direct seeding was compared with transplanting in experiment 5. Three sources of *Rhizobium leguminosarum* also were tested in this experiment.

SUMMARY AND CONCLUSIONS

Grasses and associations of legumes and grasses were grown in sand cultures. Excretion was determined by observing whether the associated nonlegume benefited during growth and by nitrogen

analyses of the plants in some of the experiments. The effect of a number of differences in experimental procedures and growth conditions upon nitrogen excretion was tried, including different plant associations, variations in potassium supply, planting method and day length, different sources of legume organisms, addition of a commercial vitamin B_1 preparation, addition of sterile and unsterile soil, and a variety of carefully controlled conditions including abrupt changes in day length and temperature during the state of rapid growth.

Grasses benefited six times in 157 associations with legumes, 114 of which were combinations of hairy vetch and Balbo rye. The evidence for excretion in two of the six cases is inconclusive. The gain by the nonlegume did not exceed 2.5 mgm of nitrogen per container in the other four instances, whereas approximately 40 mgm of nitrogen were fixed per container. Excretion, at most, was infrequent and of insignificant amounts.

Addition of soil to some of the sand cultures did not result in transfer of fixed nitrogen to the nonlegume until a late growth stage in the legume.

LITERATURE CITED

1. BOND, G., AND BOYES, J. Excretion of nitrogenous substances from root nodules: observations on various leguminous plants. Ann. Bot. (n.s.), 3: 901–914. 1939.
2. BURK, DEAN, AND BURRIS, R. H. Biochemical nitrogen fixation. Ann. Rev. Biochem., 10:587–618. 1941.
3. LUDWIG, C. A., AND ALLISON, F. E. Further experiments concerning diffusion of nitrogenous compounds from healthy legume nodules or roots. Amer. Jour. Bot., 27:719–25. 1940.
4. O'BANNON, L. S. A laboratory for use in determining the influence of various temperatures and relative humidities on the final quality of air-cured tobacco. Heating, Piping, and Air Conditioning, 2:699–702. 1939.
5. VIRTANEN, A. I. Cattle Fodder and Human Nutrition. Cambridge: Cambridge University Press. 1938.
6. ————, AND LAINE, T. The root-nodule bacteria of leguminous plants. XXII. The excretion products of root nodules. The mechanism of nitrogen fixation. Biochem. Jour., 33:412–427. 1939.
7. WILSON, P. W. The biochemistry of symbiotic nitrogen fixation. Madison: University of Wisconsin Press. 1940.
8. ————, AND WYSS, O. Mixed cropping and excretion of nitrogen by leguminous plants. Soils Sci. Soc. Amer. Proc., 2:289–297. 1938.
9. WYSS, ORVILLE, AND WILSON, P. W. Factors influencing excretion of nitrogen by legumes. Soil Sci., 52:15–23. 1941.

EFFECTS OF EARLY TOPPING ON RATOONED AMERICAN-EGYPTIAN COTTON[1]

R. H. PEEBLES[2]

RATOONED American-Egyptian cotton differs from the annual growth in staple length, lint percentage, seed fuzziness, and a number of other characters. This was demonstrated in a recent publication on ratooned S × P cotton (4).[3] The authors suggest that the ratooned cotton reacted to the environmental conditions prevailing when it flowered, flowering having begun about a month earlier than in the annual cotton. This raises the question whether or not ratooned plants, resuming growth in spring on fully developed root systems, would behave differently than seeded cotton if the flowering periods of the two were to coincide.

With that consideration in mind, an experiment to effect a material delay in the development of ratooned cotton, so that it would begin flowering at about the same time as annual cotton, was carried out at Sacaton, Ariz. The means utilized for delaying the crop was early topping, or the removal of all new growth shortly after the first flowers appeared.[4] A better method for making such a comparison is to plant the annual cotton early enough for its flowering period to coincide with that of the ratooned growth, but it is not possible to follow this procedure except in a frost-free locality.

MATERIAL AND METHODS

A plot of Amsak, an American-Egyptian variety similar in most of its plant characters and reactions to the commercial S × P cotton, was available for the experiment. The plot contained six rows of stubble and was 1,250 feet in length, or long enough for 12 100-foot sections plus a buffer at each end.

The dead stalks of the previous crop were cut back in early spring to within a few inches of the ground, which is the common local practice. New growth did not start as soon as desired for high yield, as the first irrigation was unavoidably delayed until April 22. Nevertheless, the first flowers appeared on May 13, 1943, 30 days earlier than in 1942 when the plants were grown from seed.

On May 20, one week after the first flowers appeared, all the plants in six alternate sections of the ratooned plot were topped by hand to within a few inches of the ground, resulting in the removal of virtually all new growth, which at that time ranged from 18 to 30 inches in height. On June 22, 33 days after treatment, the topped plants were about half as tall as the untreated ones and they appeared

[1]Contribution from Division of Cotton and Other Fiber Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture, Sacaton, Ariz. Received for publication September 5, 1944.

[2]Agronomist

[3]Figures in parenthesis refer to "Literature Cited", p. 95.

[4]One of the measures employed in controlling the pink bollworm is to prolong the flower-free period in spring. Ratooning has been discouraged or prohibited in areas under quarantine, but it is possible that ratooned cotton could be grown successfully, without interfering with control measures, if flowering were delayed by topping. Such drastic treatment as that given the cotton in the present experiment, which was not topped until the week after the first flowers appeared, certainly would be an uneconomic practice for commercial growers. In order to avoid serious loss in yield the topping operation would have to be done no later than necessary to delay flower appearance until the date fixed by the quarantine regulations.

to be in approximately the same stage of development as seeded American-Egyptian cotton planted not later than April 1. There were a few flowers but no bolls. The untreated plants at that time were not only flowering heavily but already had set a good crop of bolls.

Seed cotton samples were picked from the untreated sections August 23 and from the later maturing topped sections September 24. Each sample contained 50 bolls. The methods used in analyzing the seed cotton samples were the same as those followed in the comparison of ratooned and annual S × P cotton carried out in 1941 (4).

EXPERIMENTAL RESULTS

The effects of early topping on the ratooned plants (1943) are summarized in Table 1, where for comparison there also are given the corresponding means for the annual and ratooned S × P cotton of 1941 (4).

The untreated sections of the ratooned Amsak cotton yielded at the rate of 473 pounds of lint per acre, as compared with 272 pounds from the topped sections. The latter, however, were not only less productive by reason of the topping treatment, but they also suffered from a heavy infestation of *Lygus* bugs and stinkbugs.

Analysis of the samples from the topped cotton showed that it resembled annual rather than ratooned cotton in most characteristics. Lint percentage dropped from 33.8 in the untreated cotton to 30.4 in the topped and lint index from 6.0 to 5.4; staple length increased from 44.0 thirty-seconds inches in the untreated to 47.3 thirty-seconds in the topped, seed fuzz index from 0.20 to 0.47, seed index from 11.8 to 12.4, and fiber fineness from 3.50 to 3.55 micrograms per inch of fiber. These differences, as well as the difference in yield, correspond remarkably well to the differences that were found between the annual and ratooned S × P in 1941. The increase in staple length and seed fuzziness and the decrease in lint percentage and lint index in the topped cotton are so great as to be especially noteworthy.

Fiber strength, boll size, and number of seeds per boll departed from expectation. The fiber strength indexes of the samples of topped and untreated cotton, respectively, were 11.21 and 10.82. In the topped cotton 169 bolls were required to make 1 pound of seed cotton, as compared with only 150 bolls per pound in the untreated, and the bolls of the topped sections contained 15.1 seeds each, or 1.8 seeds fewer than the bolls of the untreated cotton.

The fact that the bolls from the topped plants were smaller and the seeds fewer (highly correlated characters) can be attributed to the boll damage caused by hemipterous insects that invaded the plot in unprecedented numbers in July and August. The untreated plants, having an initial advantage of almost five weeks, avoided the worst of the infestation and comparatively few of their bolls showed injury. Therefore, of the 10 characters under consideration only fiber strength can be considered definitely at variance with the trend of the experiment.

DISCUSSION

The superior strength of the fiber from the topped plants is anomalous, especially since the fiber was more than 3/32 inch longer

TABLE 1.—*Comparison of topped and untreated ratooned Amsak cotton with annual and ratooned S × P.*

Character	Amsak (1943)				S × P (1941)			
	Ratooned, topped, mean	Ratooned, untreated, mean	Difference (topped – untreated)		Annual untreated, mean	Ratooned, untreated, mean	Difference (annual – ratooned)	
			Found	Required*			Found	Required*
Yield lint per acre, lbs	272	473	–201	86	165	219	–54	38
Bolls per pound, number	169	150	+19	21	140	156	–16	14
Seeds per boll, number	15.1	16.9	–1.8	1.5	17.6	16.4	+1.2	1.0
Seed index†	12.4	11.8	+0.6	1.0	13.3	12.2	+1.1	0.5
Seed fuzz index†	0.47	0.20	+0.27	0.07	0.58	0.39	+0.19	0.09
Lint percentage	30.4	33.8	–3.4	0.8	28.9	32.0	–3.1	1.2
Lint index†	5.4	6.0	–0.6	0.6	5.4	5.8	–0.4	0.4
Staple length, 1/32 inch	47.3	44.0	+3.3	0.7	49.2	46.4	+2.8	1.0
Fiber strength, Pressley index	11.21	10.82	+0.39	0.29	9.76	10.08	–0.32	0.23
Fiber fineness, micrograms per inch of fiber	3.55	3.50	+0.05	0.11	3.65	3.58	+0.07	0.07

*Difference required for significance at odds of 99 to 1.

†Seed index is the weight of 100 ginned seeds, seed fuzz index is the weight of the fuzz on 100 seeds, and lint index is the weight of the fiber on 100 seeds, all weights in grams.

than the fiber of the untreated cotton, for as a rule "growth factors that produce greater length than is normal for a variety produce poorer structure and less strength . . . conditions that tend to produce shorter fiber favor the production of better structure and strength" (5).

The distinct difference in the main flowering periods of the topped and untreated Amsak cotton naturally leads to a consideration of climatic factors. Meteorological data for the months of June, July, and August are arranged in Table 2. The data for June and August, respectively, offer a good comparison of the seasonal conditions affecting the untreated and the topped cotton. Conditions in July can be of little comparative value since both the untreated and the topped cotton flowered freely in that month. The comparison of climatic conditions in June and August can be extended to ratooned and annual American-Egyptian cotton grown in southern Arizona in any normal season, as the seasonal trend in 1943 was not materially different from the average (Table 2).

TABLE 2.—*Meteorological data for the main flowering periods of topped and untreated cotton in a plot of ratooned Amsak, Sacaton, Ariz., 1943.*

Weather phenomenon	Flowering period untreated cotton*			Difference between June and August
	June	Flowering period topped cotton*		
		July	August	
Mean maximum temperature, °F:				
1943	100.2	104.7	98.3	+1.9
1910–1943	102.0	103.0	100.7	+1.3
Mean minimum temperature, °F:				
1943	64.3	72.8	73.1	–8.8
1910–1943	64.3	73.7	72.7	–8.4
Mean temperature, °F:				
1943	82.2	88.7	85.7	–3.5
1910–1943	83.1	88.3	86.7	–3.6
Precipitation, inches:				
1943	0.04	0.00	3.64	–3.60
1910–1943	0.13	1.56	1.56	–1.43
Evaporation from an open tank, inches:				
1943	10.04	9.83	8.85	+1.19
18-year period ending with 1943	9.44	9.12	7.90	+1.54
Mean daylight period, minutes	858	845	801	+57

*These limits are fixed arbitrarily to correspond with monthly weather summaries. As a matter of fact, the untreated cotton began flowering in May and had set most of its crop by the middle of July, and the topped cotton flowered lightly in the latter part of June and continued into September.

Maximum temperatures in June were 1.9 degrees higher than in August, minimum temperatures 8.8 degrees lower, and the mean temperature 3.5 degrees lower. Rainfall in June was negligible, whereas in August precipitation totaled 3.64 inches. Evaporation from an open tank was 10.04 inches in June, as compared with 8.85 inches

in August. Averages for the period from 1910 to 1943 give an indication of the normal summer climate at Sacaton.

Evaporation from an open tank, which reflects the interrelation of relative humidity, temperature, wind velocity, and sunshine, probably is a good measure of atmospheric conditions conducive to distress in fruiting cotton plants in hot desert regions (2). Eaton and Belden (1) state that cotton plants in the Southwest frequently show considerable wilting on hot dry days even though there is an abundant supply of moisture in the soil, confirming a similar observation by King (3). The fact that evaporation in June exceeded evaporation in August by 13% would indicate that the early-flowering untreated plants were subjected to a degree of stress not endured by the topped plants, which did not flower freely until July and August.

The behavior at Sacaton of certain vigorous perennial varieties from Peru, which suspend flower production in midsummer, suggests that cotton may not be entirely insensitive to variations in length of day. Since the average daylight period in June exceeds that of August by approximately 1 hour per day, it is possible that the untreated Amsak plants, in full flower during June, reacted to the greater exposure to sunlight. At least, the longer days accentuated the effects of the hot dry June weather.

Of the meteorological factors that have been taken into consideration, evaporation from an open tank and length of day differed greatly in June and August and are suspected of having had a bearing on the differences found between the topped and untreated Amsak in 1943. Furthermore, it is assumed that the factors operative in 1943 may similarly affect cotton in any season in southern Arizona, since the climatic progress in 1943 was not materially different from the average.

SUMMARY

Alternate sections in a plot of ratooned Amsak (American-Egyptian) cotton were materially delayed by removal of the new growth from the plants on May 20, 1943, one week after the first flowers appeared. The initial delay amounted to nearly five weeks. Consequently, the topped ratooned Amsak reached the flowering stage at about the same time as annual American-Egyptian cotton.

Samples from the topped plants definitely resembled annual cotton in respect to most characters, as compared with the untreated cotton, although the fiber was stronger and the bolls were smaller and fewer seeded than in the cotton that was not topped. Insect damage in the retarded topped cotton probably accounts for the smaller bolls and fewer seeds in the bolls, leaving fiber strength as the sole unqualified exception to the trend of the experiment.

Differences in yield, lint percentage, lint index, staple strength, seed fuzziness, seed index, and fiber fineness agree well with corresponding differences previously found between annual and ratooned S × P cotton.

The mere fact that ratooned cotton developes new aerial parts from a fully developed root system does not in itself seem to have important effects on the seed cotton and fiber characters.

On the contrary, the semblance of annual cotton observed in the samples from the ratooned plants that were delayed by early topping indicates that the distinguishing characteristics of ratooned cotton may be determined to some extent by the climatic factors that prevail during the main period of reproductive activity, modified by other factors, such as the relative scarcity in early summer of insects that cause shedding and boll injury.

Seasonal climatic factors apparently involved are drying atmospheric conditions, as measured by evaporation from an open tank, and length of day, both reaching their maxima in June, the month during which ratooned cotton flowers most freely in southern Arizona.

LITERATURE CITED

1. Eaton, F. M., and Belden, G. O. Leaf temperatures of cotton and their relation to transpiration, varietal differences, and yields. U.S.D.A. Tech. Bul. 91. 1929.
2. Fulton, H. J. Weather in relation to yield of American-Egyptian cotton in Arizona. Jour. Amer. Soc. Agron., 31:737–740. 1939.
3. King, C. J. Water-stress behavior of Pima cotton in Arizona. U.S.D.A. Bul. No. 1018. 1922.
4. Peebles, R. H., and Fulton, H. J. Ratooned S × P cotton. U.S.D.A. Circ. No. 693. 1944.
5. Salter, R. M. Report of the Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration. 1943. 1943.

REPRODUCTION AND POLLINATION STUDIES ON GUAYULE, *PARTHENIUM ARGENTATUM* GRAY AND *P. INCANUM* H. B. K.[1]

LeRoy Powers and Reed C. Rollins[2]

THE previously available information on the method of reproduction and the method of pollination in guayule, *Parthenium argentatum* Gray, is both confusing and conflicting. Kokieva (12)[3] says, "As regards pollination, observations on the morphology of the guayule inflorescences confirmed likewise by some biological data make us consider this plant as a cross pollinating one". In contrast to this statement is that of Pissarev (18) which is as follows: "For the purpose of finding the most expedient method of breeding we have investigated the biology of flowering and the pollination in the guayule. In the result of these experiments it has been established that for practical purposes, the guayule may be regarded as a self-pollinated plant, though the possibility of cross-pollination is not excluded". Probably the most critical work on the method of pollination in guayule is that of Kalashnikov (10). He found that guayule under the conditions of Kara-Kala to be intermediate between the self-pollinated and cross-pollinated plants. Kirkwood (11) makes the following statement: "Pollination is effected and fertilization occurs in the usual manner as indicated by the presence of the pollen-tube, the development of glandular tissue at the mouth of the micropyle, influencing apparently the growth of the pollen-tube, and the almost constant occurrence of embryos in the earlier stages of development". From studies on the development of the female gametophyte in *P. argentatum* Kokieva (13) also came to the conclusion that reproduction is sexual; but points out that since fusion of the male gamete and the egg has not been observed, further work is necessary. Dianova, Sosnovetz, and Steshina (5) from embryological and controlled pollination studies concluded that normal sexual reproduction takes place in guayule. Some attempts at hybridization conducted by W. B. McCallum (unpublished) indicated that apomixis may be occurring in at least some strains.

It is apparent that the previously available information is not adequate, and therefore critical and discriminatory studies on reproduction and pollination in *P. argentatum* and *P. incanum* are essential for the development of an effective breeding program. The purpose of this article is to report the results from studies concerning the methods of reproduction and methods of pollination in guayule, *P. argentatum*, and mariola, *P. incanum*.

---

[1]Contribution from the Guayule Research Project, U. S. Dept. of Agriculture, Agricultural Research Administration, Bureau of Plant Industry, Soils, and Agricultural Engineering, Salinas, Calif. Received for publication September 5, 1944.

[2]Principal Geneticist and Associate Geneticist, respectively. The senior author wishes to express his appreciation to Dr. A. D. Bergner for the determination of the chromosome numbers for the intraspecific studies.

[3]Figures in parenthesis refer to "Literature Cited", p. 112.

The investigations on reproduction and pollination in *P. argentatum* and *P. incanum* were divided into two parts namely, intraspecific pollinations and interspecific pollinations. The experimental results will be presented under these two main headings.

INTRASPECIFIC POLLINATIONS

MATERIAL AND METHODS

For a general description of the inflorescence, the morphology of the flower, and the seed (achene) the reader is referred to Lloyd (14).

Both greenhouse and field studies were conducted. The greenhouse studies were started in the winter of 1942–43; whereas, the field studies were started in the summer of 1943. In the greenhouse the following plants were used and the indicated pollinations were made: 593–9 ♀ × 49–2 ♂ and reciprocal; 444–7 ♀ × 49–1 ♂ and reciprocal; 444-8 ♀ × 427–5 ♂ and reciprocal; 406–12 ♀ × 427–6 ♂ and reciprocal.

Since so few seeds were obtained when 49–1 or 49–2 were used as the maternal plant, the data for these particular crosses are not included. The following six different treatments were employed:

1. The florets of the capitula were not treated. The flowering branches were merely appropriately labeled.
2. The florets of the capitula were brushed with a camel hair brush during anthesis. After brushing the stigmas of the florets, an adequate sample was examined to assure that pollen was adhering to them.
3. The capitula were emasculated but not covered with a percale bag nor were the ray florets pollinated.
4. The capitula were emasculated by removing the disc florets and all the capitula of the flowering branch were covered with a percale bag. The capitula were not re-examined. Pollen was not applied to the stigmas of the ray florets.
5. The capitula were emasculated by removing the disc florets, the capitula of the flowering branch were covered with a percale bag and pollen collected from the same plant was applied daily to the stigmas of the ray florets until the latter had turned brown. At the time of pollination the capitula were examined for disc florets that might have been missed during emasculation, and any found were removed before dehiscence.
6. The capitula were emasculated, the capitula of the flowering branch were covered with a percale bag, and pollen from the male plant was applied daily until the stigmas had turned brown. Each day before applying pollen the capitula were examined for any disc florets that might have been missed during the first emasculation. Any such florets were removed before the anthers had dehisced.

To avoid confounding, any differences arising from the above given treatments with time of treatment and age of plant, six flowering branches of the same stage of maturity were selected and labeled according to strain and plant number, date of treatment, and treatment. Flowering branches of any given plant were selected for treatment only when it was possible to select six (or some multiple thereof) having the same approximate degree of maturity. Each flowering branch was reduced to five capitula in case more were present.

At this time it is well to consider how these six treatments may be expected to provide information on the method of reproduction and the mode of pollination in *P. argentatum*. Treatment 1 serves as a standard (check) for the other five treatments. Treatment 2 furnishes evidence whether the percentage of viable seed is increased by assuring that pollen of a given plant gets on the stigmas of the florets from the same plant. Treatment 3 provides evidence as to whether the florets from emasculated capitula receive pollen from surrounding capitula. Also, this treatment may furnish information as to the effect, if any, of emasculation (removing the disc florets) upon the formation of viable seed. Treatment 4, in comparison with treatments 5 and 6, furnishes information as to whether pseudogamy is occurring. Treatment 5 provides evidence as to the effectiveness of the plant's own pollen in bringing about the formation of viable seed, and also in comparison with other treatments should yield some information as to the effect of emasculation and the percale bag upon the formation of viable

seed. Treatment 6 should furnish information as to the effectiveness of the pollen from the male plant in bringing about seed formation, and together with a test of the progeny resulting from self-pollinations and reciprocal cross-pollinations, furnishes information as to the method or methods of reproduction occurring in these plants of *P. argentatum*.

To determine the proportion of viable seeds for the various treatments, germination studies were conducted. The design of the experiment was a randomized complete block, there being 10 blocks with 25 seeds per block, making a total of 250 seeds per variate. The seed was left in the germinator for a period of 21 days, during which daily germination records were taken. Each day those that had germinated were removed from the blotters and the progeny resulting from self-pollinations and reciprocal cross-pollinations to be tested further were transferred to individual pots and placed in the greenhouse. At the end of the 21-day period the number of the remaining seeds possessing cotyledons and presumably embryos was determined. These potted plants were transplanted from the greenhouse into the field on May 17, 1944.

In order to obtain information concerning the method or methods of reproduction occurring, it is necessary to classify as to phenotype those progenies resulting from self-pollinations and reciprocal cross-pollinations. The general characteristics of each plant together with a detailed study of certain characters were used in classifying the plants as to whether the phenotype was that of the maternal plant, and in those instances in which such was not the case, in further classifying them as to whether they showed any characteristics of the pollen plant. The depth and angle of the cleft of the corolla, together with the size and shape of the corolla, was found to be very helpful in making the phenotypic classifications. Also, the characteristics of those leaves formed after the plant had been growing for some time were found to be particularly helpful. In using leaf characters it is desirable, if not essential, that the plants be of the same age. Such was the case in these studies. Trichome-characteristics (Rollins, 19) were found to be helpful also. A comparison of the length of the short arm (based on attachment point) of the trichome adjusted for the total length of the trichome by the method of regression was found to add considerably to the reliability of the classification.

Also, the plants were classified as to chromosome group. Bergner (1) and Stebbins (24) found that the collections of guayule from Mexico and the Trans-Pecos area of Texas fall into three major groups, in which $2n = 36+$, $54\pm$ and $72\pm$. As indicated by the $+$ and $\pm$ symbols deviations from these numbers occur. Consequently, the possible effects due to aneuploidy must be kept in mind when making the phenotypic classifications. The chromosome group to which the plant belonged was determined by making counts and by diameter measurements of the pollen.

Aberrant plants which influenced the classification were found among the progeny of the $54\pm$ and $72\pm$ chromosome groups. The characteristics of these aberrant plants were as follows: Growth was generally slow and irregular. The leaves have an irregular pattern, a strap-like appearance, and are thicker than the leaves of the normal plants of the same populations. In addition, the pollen grains and capitula are larger and the peduncles are thicker. In every case these aberrant plants counted from the $54\pm$ group had $81\pm$ chromosomes and in all but a very few cases those counted from the $72\pm$ group had $108\pm$ chromosomes. Rarely, but in a few instances the aberrant plants from the $72\pm$ group were found to be aneuploids of that group.

In making the classifications it was necessary to have the following in mind. The parental material probably is heterozygous for the genes differentiating a number of the characters. Also, it seems probable that polyploidy, aneuploidy, loss of chromatin, and other cytological irregularities are causing variability among the plants of these progenies. One other fact should be mentioned. Among the 152,000 plants examined in the field three chimeras were found, showing that genetic variability arises during growth of the plant. This source of variability has very little, if any, bearing on the classification and in respect to guayule probably very little importance as a method of plant breeding. The differences between the plants used in self-pollinations and reciprocal cross-pollinations were of sufficient magnitude so that the variability noted did not prohibit an accurate classification of the plants, but an appreciation of the fact that this variability was to be expected aided in making the classifications.

EXPERIMENTAL RESULTS

Table 1 gives the percentage of seeds that germinated among a total of 250, the data being classified according to treatment and plants. From the data the following conclusions can be drawn:

Brushing of the nonisolated capitula (treatment 2) increases the percentage of viable seed. The emasculated and nonbagged capitula (treatment 3) produced almost as many viable seeds as the non-emasculated capitula, showing that pollination occurred under these conditions.

The data concerning treatment 4 need to be considered in detail. In this treatment the capitula were emasculated and the five capitula of a flowering branch were covered with a percale bag, but pollen was not applied to the stigmas of the ray florets. The strains averaged 0.7% of viable seeds and in this respect there were no significant differences between plants. This could be interpreted in one of three ways; that apomixis was occurring, that emasculation was not complete, or that the isolator employed was not completely effective. Incomplete emasculation was suspected since in making the pollinations for treatments 5 and 6 it was found that occasionally disc florets had been missed at the time of emasculation, due presumably to their slow development. They were undersize. In case of treatments 5 and 6 these were removed before dehiscence. However, since the emasculated and bagged capitula (treatment 4) were not examined after once having been bagged, it seems probable that enough of these small disc florets were missed to allow the development of the percentage of viable seeds noted. To further check this supposition another experiment was conducted in which both kraft paper and percale bags were used as isolators. The data and method of treatment are given in Table 2. In this experiment, to assure that all disc florets had been removed, the emasculations were checked repeatedly until the stigmas of the ray florets had turned brown. From these data it is evident that apomixis without pollination is not occurring. In other words, if apomixis is occurring, pseudogamy (for definition see Sharp, 22, page 406) must be involved also. In addition these data show that both the kraft paper and percale isolators are entirely effective in controlling pollination.

From the data for treatment 5 of Table 1 it can be seen that self-pollination for all these plants is effective in bringing about the production of viable seed. Moreover, neither bagging nor emasculation seems to have any appreciable adverse effects on the formation of viable seed. The data show that 427–5 and 427–6 do not produce as high a percentage of viable seed when self-pollinated as when pollination is not controlled, indicating that all pollen is not equally effective in bringing about the production of viable seed.

The results with cross-pollination (treatment 6) are very similar to those for self-pollination, in that the averages for the two treatments are not significantly different. However, there is an interaction for treatments and plants. That is, all treatments do not produce analogous results for all plants. The percentage of viable seeds for 444–7, 427–5, and 427–6 were significantly less for the controlled cross-

TABLE 1.—*The percentage of seeds germinated among a total of 250, the data being classified according to treatment of the capitula and according to plants.*

Treatment of the capitula	Strains and plants*						
	593–9	444–7	444–8	427–5	427–6	406–12	Treat-ment average
1. No treatment	54±3.1	36±3.0	38±3.1	38±3.1	33±3.0	36±3.0	39±1.3
2. Capitula brushed					38±3.9	50±3.2	
3. Emasculated only	31±2.9	21±2.6	38±3.1	45±3.2	41±3.1	32±3.0	35±1.2
4. Emasculated and bagged	0.8±0.6	0.4±0.4	0.4±0.4	0.8±0.6	0.8±0.6	1.2±0.7	0.7±0.2
5. Emasculated, bagged and self-pollinated	28±2.8	46±3.2	47±3.2	28±2.8	22±2.6	41±3.1	35±1.2
6. Emasculated, bagged and cross-pollinated	44±3.1	34±3.0	44±3.1	18±2.4	15±2.3	43±3.1	33±1.2
Plant average†	32±1.3	27±1.3	33±1.3	26±1.2	22±1.2	31±1.3	29±0.5

*Plant 593–9 was pollinated with 49-2 and plant 444-7 with 49-1. Plants 444-8 and 427-5 represent reciprocal cross-pollinations as do 427-6 and 406-12.
†Capitula brushed not included in average.

TABLE 2.—*Number and percentage of seeds possessing cotyledons and presumably embryos in plants of guayule not isolated and isolated, showing the effectiveness of emasculation and the isolators employed.*

Plant No.	Self-pollinated; brushed and not bagged			Non-pollinated					
	Total number of seed	Seeds with cotyledons and presumably embryos		Capitula emasculated and kraft bagged			Capitula emasculated and percale bagged		
				Total number of seed	Seeds with cotyledons and presumably embryos		Total number of seed	Seeds with cotyledons and presumably embryos	
		Number	%		Number	%		Number	%
406–12	384	223	58.1 ±2.52	385	0	0	385	0	0
444–8	260	161	61.9±3.01	260	0	0	259	0	0
427–6	710	375	52.8±1.87	706	0	0	710	0	0
427–5	709	350	49.4±1.88	709	0	0	709	0	0
Total	2,063	1109	53.8±1.10	2,060	0	0	2,063	0	0

pollinations than for the controlled self-pollinations. This was not true for plants 593-9, 444-8, and 406-12. Such results clearly demonstrate that all pollen is not equally effective in bringing about the production of viable seed.

It will be remembered that a proportion of the progenies from the controlled self- and cross-pollinations were grown for phenotypic classification. The number of plants nondistinguishable from the maternal phenotype and the number of plants distinguishable from the pollen plant are given in Table 3. The most striking fact of these data is, that regardless of which plant is maternal, 84% or more of the progeny have a phenotype nondistinguishable from that of the maternal plant. This, together with the data of Tables 1 and 2, furnishes conclusive evidence that nonsegregating apomixis is the predominating method of reproduction in these plants and that pseudogamy is occurring; that is, pollination is necessary for the development of viable seed. Further, the fact that these plants (323 individuals of column 2, Table 3) which have a phenotype nondistinguishable from that of their maternal plant possess the chromosome number of that plant shows that nonreduction is occurring. Then the method of reproduction giving rise to these individuals is "nonreduced (2n) pseudogamy".

TABLE 3.—*Classification of the individual plants according to whether they are cross- or self-pollinated, whether their phenotype is or is not distinguishable from that of the maternal plant, whether they show any differential characteristics of the pollen plant, and finally according to the chromosome group to which they belong.*

Cross- or self-pollinated plant	Non-distinguishable from maternal phenotype 72±	Distinguishable from the maternal phenotype					
		No differential characteristics of pollen plant			Some characteristics of pollen plant		
		36+	72±	108±	36+	72±	108±
427-6, self-pollinated (72±)...........	31	0	3	1	0	0	0
427-6 × 406-12.....	37	0	0	0	0	1	0
406-12 × 427-6.....	44	0	0	0	0	6	1
406-12, self-pollinated (72±)...........	39	0	2	1	0	0	0
427-5, self-pollinated (72±)...........	48	0	1	0	0	0	0
427-5 × 444-8......	31	0	0	0	0	0	0
444-8 × 427-5......	36	0	1	0	0	0	0
444-8, self-pollinated (72±)...........	57	0	0	2	0	0	0
Total..............	323	0	7	4	0	7	1

Additional information concerning the methods of reproduction occurring in these plants can be obtained from the detailed classification of those plants having phenotypes distinguishable from that

of the maternal plant. The plants of this class were further divided into those showing no differential characteristics of the pollen plant and those showing some differential characteristics of the pollen plant. Each of these is again subdivided into those having 36+, 72±, and 108± chromosomes. In considering these chromosome groups it must be kept in mind that the chromosome number within a group is not the same for all plants. That aneuploidy occurs, must be taken into account.

First, these data will be examined to determine whether sexuality is occurring. Since the plants used in any given set of reciprocal cross-pollinations differed greatly, the two sexual progenies, if any, resulting from self-pollinating the plants should be phenotypically distinguishable. That is, no overlapping segregation would be expected. From the data given in columns 3, 4, and 5 of Table 3 it can be seen that in no case did those individuals arising from self-pollination and which have phenotypes distinguishable from the maternal phenotype show any differential characteristics of the pollen plant used in corresponding reciprocal cross-pollinations. Moreover, a detailed examination of the characters of these plants revealed that in every case they were phenotypically distinguishable from the progeny resulting from self-pollinating the pollen plant. Consequently, the conclusion reached is that there was no overlapping segregation between the progenies resulting from self-pollinating the plants of any given set of reciprocal cross-pollinations. However, it should be pointed out that the individuals of any one progeny differed among themselves, proving that the plants are heterozygous as was suspected. These facts, together with the information that no viable seed was formed (data of Table 2) by the nonpollinated florets of these same plants, furnish conclusive proof that the seven individuals in column 7 of Table 3, since they have 72± chromosomes, arose as a result of normal sexual reproduction (reduction followed by fertilization). Then it follows that the first six individuals of column 4 of this same table arose as a result of normal sexuality, also. Finally, since it has been established that nonreduced (2n) pseudogamy and sexuality occur, the obvious and logical conclusion is that the 108± chromosome individuals in this material arise as a result of abnormal sexuality (nonreduction followed by fertilization).

There remains one plant of Table 3 whose origin has not been explained. This is the 72± chromosome plant of the cross-pollination 444-8 × 427-5. It is phenotypically distinguishable from the maternal plant but does not have any of the differential characteristics of the pollen plant. The fact that its phenotype is significantly different from that of the maternal plant shows that it could not have arisen as a result of nonreduced (2n) pseudogamy. Likewise, the fact that it has no differential characteristics of the pollen plant makes improbable the supposition that it arose as a result of normal sexuality. Abnormal sexuality (nonreduction followed by fertilization) is ruled out by the chromosome number of the plant, 72±. The genetic segregation necessary to account for this plant could have taken place if it had arisen through diplospory (for definition see Stebbins, 23, page 511). An alternative explanation would be that

this plant arose sexually as a result of self-pollination. However, this seems highly improbable, since the emasculated ray florets cross-pollinated at the time of each pollination were examined for any disc florets that had not been removed previously. The data of Table 2 show that when such a procedure was followed pollination was effectively controlled. Then, it seems probable that "pseudogamous diplospory" occurs occasionally in some plants of guayule.

That 36+ chromosome individuals occur among the progeny of the 72± group has been shown by Bergner (1). To date, four plants with reduced (1n) chromosome number have been found in the field plantings of those plants grown from the seed collected from Mexico and the Trans-Pecos area of Texas. Three of these were derived from seed of individual plants growing on the 02 Ranch in Texas, and one was derived from seed of nonselected plants growing near Shafter, Texas. Still another plant with the 1n number of chromosomes was found among the plants of variety 406 which are being grown as a standard in the experiments involving the various collections. The occurrence of plants with reduced (1n) chromosome number among the progeny of 72± (2n) chromosome individual-plant selections is strong evidence that "reduced (1n) pseudogamy" is occurring to some extent in this material.

Conclusions to be drawn from the above facts, having a bearing on the methods of reproduction occurring in *P. argentatum*, may be summarized by the following classification based on the origin of the progeny:

METHODS OF REPRODUCTION

Amphimixis	Normal sexuality (reduction followed by fertilization)	
	Abnormal sexuality (non-reduction followed by fertilization)	
Apomixis	Non-segregating	Non-reduced (2n) pseudogamy
	Segregating	Reduced (1n) pseudogamy Pseudogamous diplospory

All of the methods of reproduction listed above may occur in the production of the progeny from an individual plant.

To obtain some information as to the mode of pollination in guayule, flowering branches of five xanthous plants from collection 4255 (36+ chromosomes) were percale bagged and brushed to assure self-pollination, and others of the same plants were selected for noncontrolled pollinations. The total number of plants was 703 for the five progenies grown from seed arising from noncontrolled pollinations. The average percentage of xanthous plants was 10.0 ± 1.13 and the range in percentage of xanthous plants was from 0.4±0.38 to 17.0±3.19. The balance of the 703 plants was of normal green color. Only four plants were obtained from over 1,000 seeds arising from self-pollinations. All four of these plants were xanthous and

were the progeny of one plant. The combined data from noncontrolled pollinations and controlled self-pollinations show that the maximum percentage of the progeny that could be resulting from some form of apomixis is 10. Since these plants were in proximity to xanthous plants and plants heterozygous for the gene pair or gene pairs differentiating xanthos from normal green, it seems probable that the xanthous plants arose as a result of cross-pollination rather than as a result of apomixis. Such being the case, the logical conclusion from these studies on pollination is that these five plants are almost if not entirely cross-pollinated.

Also, information having a bearing upon self-incompatability in guayule was obtained from studies conducted with the 36+ chromosome collections made from natural populations of guayule growing in Mexico and the Trans-Pecos region of Texas. Only $0.6 \pm 0.13\%$ of the seeds produced by self-pollinating some plants of all these 36+ chromosome collections produced seedlings; whereas, $22 \pm 0.42\%$ of the seeds arising from noncontrolled pollinations of these same plants produced seedlings. Percale bags were used as isolators in the self-pollinations and brushing of the bagged capitula was practiced to assure pollination. The figure of $0.6 \pm 0.13\%$ is very close to that of 0.5% reported by Kalashnikov (10). That the pollen of these plants is viable was shown by microscopic examinations of the pollen and by cross-pollination studies. The pollen was found to have a high percentage of filled pollen grains and to be very effective in bringing about the production of viable seeds when placed on the stigmas of other plants. These facts taken collectively prove that at least the majority of the plants of these 36+ chromosome collections possess a high degree of self-incompatibility. That comparatively speaking a fairly high degree of self-compatibility occurs in some of the 72± chromosome plants of guayule is shown by the data for the controlled self-pollinations given in Table 3. Since polyploid forms occur within the species, it is logical to assume that the different collections possess different degrees of self-incompatibility (Crane and Lawrence, 4). It must be kept in mind that self-incompatibility and self-compatibility are further complicated in *P. argentatum* by male sterility. (Unpublished data and see interspecific hybridization section of this paper). Also, aneuploidy, chromatin bridges, fragmentation and other cytological irregularities (Bergner unpublished) probably further complicate the situation. For the most important literature having a bearing upon self-sterility and compatibility, see East and Mangelsdorf (6), East and Yarnell (7), Crane (2), Crane and Lawrence (3 and 4), and for a general review of the literature Sansome and Philp (20).

INTERSPECIFIC POLLINATIONS

MATERIAL AND METHODS

The plants used in the experiments involving interspecific pollinations were handled in a manner similar to those used in the intraspecific pollinations. Isolation of groups of flower heads was accomplished by the use of percale bags and the individual heads were made unisexual by removing the disc florets. Numerous ray florets of both guayule and mariola were examined for abnormalities to see if any anthers or anther-portions were likely to develop and cause contamination, but none was found. Pollinations of given heads were made daily for several days

or until necrotic spots appeared on the stigmas. The seeds from the variously pollinated plants were sprouted in a germinator and the resulting seedlings transferred to a greenhouse for subsequent growth. Pollinations were carried on during the late summer and fall of 1943 and the seeds were germinated in December, 1943, and January, 1944. In all, 33 different crosses were attempted. In 16 of these, guayule was used as the female parent. In the other 17, mariola was used as the female. A number of different strains and collections of guayule and mariola were used in several different combinations.

Methods used in identifying natural hybrids between guayule and mariola (Rollins, 19) are equally critical when used to detect hybrids produced artificially. True hybrids between these species can be easily identified as soon as the first few leaves of a young seedling are fully expanded. The morphological differences between the hybrids and their parents are accentuated as the plants develop. These differences are so striking that the classification of the progenies into hybrid and nonhybrid groups on a phenotypic basis is relatively easy. The progenies have been grown to full flowering for chromosome and pollen studies, with the exception of a portion of the apomicts and some seedlings where germination data only were desired.

EXPERIMENTAL RESULTS

Table 4 gives data from certain pollinations between guayule and mariola. In those cases where guayule is listed as a female, mariola was used as the male parent. The reverse is true where mariola is given as the female parent. Considering first the column showing the percentage of maternals, the range is from 0 to 95% where guayule was used as the female parent and from 0 to 100% where mariola was used as the female parent. The members of a given progeny classed as maternal do not deviate from the mother plant in any significant way. They have the same type, size, and disposition of their trichomes[4] as the maternal parent and the leaf shapes and sizes are also similar as are the flower stalks and heads. The growth form is that of the maternal parent. Furthermore, none of the phenotypical characteristics of the paternal parent has been detected. The presence of these numerous strictly maternal plants in a number of progenies of both guayule and mariola, where only hybrids would be expected if the normal sexual processes were occurring, is ample evidence that sexuality is being by-passed. It is evident, therefore, that some type of apomixis is prevalent in both these species. The assumption is that the plants of this category arose from unreduced, unfertilized egg cells.

It is significant that two maternal type guayule plants with only half the expected chromosome number were derived from two separate cross-pollinations. The mother guayule plant in each case has 72± chromosomes, while the two reduced maternals have 36+ chromosomes. These two reduced maternals are similar to their respective mother plants but have smaller parts and organs throughout. They show no paternal characters from the mariola plant. Both show some irregularities during meiosis preceding pollen formation, but one plant has over 80% good pollen while the other has less than 50% good pollen. The obvious explanation of the way in which these plants arose is that reduced egg cells developed without fertilization having taken place.

[4]For information concerning the trichomes of guayule and mariola, see Rollins (19).

TABLE 4.—*Results of cross-pollination between guayule and mariola.*

Variety or accession number	Number of plants used	Number of seeds	Number of plants classified	Normal hybrids, %	Aberrant hybrids, %	Maternals, %	Number of reduced maternals
Guayule as ♀:							
2n = 36+ chromosomes							
4255	3	260	111	96.4±1.8	3.6±0.5	0	0
2n = 72± chromosomes							
42265–II	1	79	52	3.8±2.7	34.6±6.6	61.6±6.8	0
42362–I	1	82	41	22.0±6.5	12.2±5.1	63.4±7.5	1
42356–II	1	58	26	30.8±9.1	0	69.2±9.1	0
416	3	753	315	5.4±0.3	8.6±1.6	86.0±2.0	0
42286–II	1	196	45	2.2±2.2	11.1±4.7	86.7±5.1	0
42433–I	1	81	41	0	9.8±4.7	90.2±4.6	0
593	7	944	347	3.2±0.2	5.2±1.2	91.3±1.5	1
42343–I	1	30	21	0	4.8±4.7	95.2±4.7	0
Totals	16	2,223	888	5.40±0.8	8.78±1.0	85.58±1.2	2
Mariola as ♀*:							
4260–XX	1	206	24	95.8±4.1	4.2±4.1	0	0
4260–XV	1	225	11	81.8±11.6	0	18.2±11.6	0
4275–V	1	418	74	24.3±5.0	28.4±5.2	47.3±5.8	0
4230–VIII	1	164	2	50.0±35.4	0	50.0±35.4	0
43684–III	1	266	34	0	47.1±8.6	52.9±8.6	0
4260–IV	1	93	35	17.1±6.4	14.3±5.9	68.6±7.8	0
42207–IV	1	130	39	7.7±4.3	20.5±6.5	71.8±7.2	0
43684–VI	1	196	17	5.9±5.7	11.8±7.8	82.3±9.3	0
42172	3	648	116	9.5±2.7	3.4±1.7	87.1±3.1	0
4230–I	1	42	16	6.2±6.0	6.2±6.0	87.5±8.3	0
42207–XI	1	192	45	0	11.1±4.7	88.9±4.7	0
42352–II	1	186	11	9.1±8.7	0	90.9±8.7	0
42207–III	1	338	91	1.1±1.1	3.3±1.9	95.6±2.2	0
4230–IX	1	514	41	0	0	100.00	0
4260–XIII	1	93	11	0	0	100.0	0
Totals	17	3,711	567	13.40±1.4	11.64±1.3	74.95±1.8	0

*Chromosome numbers have not been determined for all of the plants of mariola listed, but 2n = 54± and 2n = 72± are known numbers for several plants.

The F_1 hybrids derived from cross-pollinations in both directions show considerable variation within progenies. However, in most of these two types of hybrids are easily distinguished. One type is normal, having well-formed leaves, balanced growth, and good vigor. The other has malformed leaves, distorted growth throughout, and poor vigor. In most cases, the latter aberrant type has larger heads, thicker leaves and flower stalks and larger pollen grains. Experience with this aberrant type plant has shown that it usually has about a one-third larger chromosome compliment than the normal type from which it is distinguished, provided the two parents possessed the same chromosome number. Otherwise the excess of chromosomes in the aberrant type hybrid over the normal hybrid depends on the number present in the maternal parent. For example, in a case where a $72\pm$ chromosome guayule plant was pollinated with a $54\pm$ mariola plant, the normal hybrids have $63\pm$ chromosomes. The aberrant hybrids so far investigated from this same cross have $99\pm$ chromosomes. This shows that it was the egg nucleus which possessed double the expected number of chromosomes and not the male nucleus.

In addition to the characteristics peculiar to the aberrant hybrids, most of these plants resemble the maternal parent more closely than do the normal hybrids. By comparing the hybrids of crosses in which two $72\pm$ chromosome mariola plants were pollinated with a $36+$ guayule plant and a $72\pm$ guayule plant, respectively, it can be shown that the balance of mariola to guayule chromosomes is important in determining the nature of the hybrids in the F_1 population. The effect of the guayule parent on the hybrids was far less marked when the $36+$ chromosome parent was used than when the $72\pm$ chromosome parent was used. Similarly, the effect of a $72\pm$ chromosome mariola on the hybrids from a $36+$ chromosome guayule is far more marked than it is on a $72\pm$ chromosome guayule. If it is assumed that the aberrant hybrids resemble the maternal parent because a large proportion of their chromosomes came from the mother plant, these facts give weight to that supposition.

A detailed study of the major trichome type found in guayule, mariola, and the hybrids of these species has given a further basis for determining the position of any given hybrid with respect to its parents. It has been found that a marked modification of both the guayule and mariola trichome type (see Rollins, 19, for illustrations) occurs in the F_1 of these species if the hybrid is normal. On the other hand, if the hybrid is aberrant, the trichome type is more nearly that of the maternal parent. The plants formerly classed as "rough aberrant" (19) are the same type as the aberrant hybrids of the present study and undoubtedly represent natural interspecific hybrids as was suggested there. For comparative purposes, the trichome illustrations (19) of the rough type plants may be used.

The disturbed growth pattern, slow growth and enlarged parts, characteristic of the aberrant types has been found to be correlated with a high chromosome number in numerous cases. However, the plants falling into this category form a complex group, and an extended cytological examination which may well turn up novelties remains to be completed. The evidence at hand indicates that the aberrant

type hybrids are predominately the product of an unreduced egg cell fertilized by a normal male gamete. The normal hybrids, on the other hand, have resulted from the fertilization of a reduced egg cell in each case.

Guayule and mariola are highly distinctive species and yet cross-pollinations between them are quite productive of viable seed when compared with self-pollinated plants of either species. Table 5 gives comparative data on a number of interspecific pollinations in both directions, together with the results of germination tests of seeds produced from the self-pollinated maternal plant of each cross.

In considering the data concerning guayule, it is important to note that in every plant tested, pollen from mariola produced more viable seed than did pollen from the guayule plant itself. The percentage of viable seed produced from interspecific pollinations where mariola was used as the pollen plant compares favorably with that of intraspecific pollinations (Table 1). Little or no reduction in viability of seed of guayule results from the use of pollen from the more distantly related plants. More extensive data would be expected to reveal some markedly incompatible plants between these two species, but we have not encountered any. In fact, on the basis of our present information, mariola or hybrids between mariola and guayule might well be seriously considered as testers for determining the amount of sexuality present in various strains of guayule.

With the exception of two plants of accession 43684, the mariola plants shown in Table 5 also gave a higher percentage of viable seed when pollinated with guayule than when they were selfed. Germinations of seeds of mariola were poorer throughout than they were for guayule. The seed of both species was treated the same, but the procedure is based upon methods devised for the handling of guayule and may not be optimum for mariola.

From the three self-pollinated 36+ chromosome guayule plants, only three seedlings were obtained. The pollen of these plants was relatively good and was applied to the stigmas in abundance several times. The selfing was carried on at the same time and under the same conditions as the corresponding cross-pollinations. It appears from our data and observations that here again is evidence for self incompatibility factors operating in the 36+ chromosome group. Some factors for self-incompatibility seem operative also in at least two plants of mariola. The self sterility indicated for the two 72± chromosome guayule plants 416–I and 416–II is of a different sort. These plants are male sterile, that is, they do not produce any normal pollen. These two plants together with randomly selected apomictic first generation 12-plant progenies from each have been examined weekly over a 4- to 6-week period for pollen production. No normal pollen was found in any case. Casual examinations were made of all the apomictic offspring of these two plants and none was found to produce any normal pollen. Very occasionally a giant misshapen grain can be found. That this type of sterility is genetic and not environmental is shown by the fact that one of three hybrids from plant 416–I is male-sterile and one out of 22 hybrids so far examined from plant 416–II is male-sterile. This is also shown by the fact

TABLE 5.—*A comparison of the number of offspring of certain plants of guayule and of mariola when selfed and when used in interspecific cross-pollinations.**

Variety or accession number	Number of plants	Selfed: Seeds, number	Selfed: Seedlings, number	Selfed: Seedlings, %	Cross-pollinated: Seeds, number	Cross-pollinated: Seedlings, number	Cross-pollinated: Seedlings, %
Guayule as ♀:							
36+ chromosome plants							
4255-II	1	68	0	0	66	12	18.2 ±4.75
4255-III	1	388	0	0	125	80	64.0 ±4.29
4255-I	1	80	3	3.8 ±2.14	69	43	62.3 ±5.83
Totals	3	536	3	0.56±0.32	260	135	51.91±3.09
72± chromosome plants							
416-I	1	123	0	0	231	54	23.4 ±2.78
416-II	1	62	0	0	522	297	56.9 ±2.17
593-9	1	84	8	9.5 ±3.20	152	21	13.8 ±2.80
593-VI	1	100	11	11.0 ±3.13	303	75	24.8 ±2.48
42265-II	1	70	19	27.1 ±5.31	79	53	67.1 ±5.29
593-V	1	77	23	29.9 ±5.21	133	71	53.4 ±4.33
42362-I	1	139	42	30.2 ±3.89	82	46	56.1 ±5.48
593-I	1	44	20	45.5 ±7.51	89	48	53.9 ±5.28
Totals	8	699	123	17.31±1.43	1,591	665	41.79±1.24
Mariola as ♀:							
4260-XX	1	193	0	0	206	43	20.9 ±2.83
4275-V	1	426	0	0	418	81	19.4 ±1.93
42172-VI	1	45	0	0	64	1	1.6 ±1.57
42207	2	824	10	1.2 ±0.37	530	172	32.5 ±2.03
42352-II	1	349	5	1.4 ±0.63	186	16	8.6 ±2.06
4230	3	2,014	48	2.4 ±0.35	720	80	11.1 ±1.17
42172-II	1	485	18	3.7 ±0.85	392	102	26.0 ±2.20
4260-XV	1	362	17	4.7 ±1.11	225	16	7.1 ±1.71
43684	2	936	273	29.2 ±1.49	462	69	14.9 ±1.66
4260-IV	1	135	49	36.3 ±4.14	93	44	47.3 ±5.18
Totals	14	5,769	420	7.28±0.35	3,296	624	18.93±0.68

*Percale bags were used to isolate the flower heads treated.

that the apomictic progeny of the two parental plants are uniformly male-sterile. Evidently the failure of pollen development in our material is similar to that reported by Kalashnikov (10).

SUMMARY AND CONCLUSIONS

The data definitely show that some plants of guayule, *P. argentatum* and mariola, *P. incanum*, are characterized by a high degree of facultative apomixis and that these apomictic plants are also pseudogamous. Also, of equal importance is the occurrence of collections of guayule which are almost if not completely sexual (in which both

reduction and fertilization are taking place). To date all of these highly sexual forms have had 36+ chromosomes and no highly facultative-apomictic plants have been found among them. However, since the studies have not been exhaustive, the occurrence of such plants among the 36+ chromosome group of guayule is possible. Also, as yet no predominantly normal-sexual plants of guayule (in which both reduction and fertilization are occurring) have been found among the 54±, 72±, and 108± polyploid groups. All the collections of these groups studied to date are predominantly facultative apomicts and are pseudogamous. Predominantly normal-sexual plants of mariola were found but were of infrequent occurrence among the collections of mariola. The evidence strongly supports the conclusion that some plants among these latter polyploid groups of guayule arise as a result of reduced pseudogamy, nonreduced pseudogamy, fertilization of reduced and unreduced gametes, and diplospory. So far, evidence has been obtained for the occurrence in mariola of only three of these types of reproduction. These are nonreduced pseudogamy, fertilization of reduced gametes, and fertilization of unreduced gametes. These are very similar to the methods of reproduction reported for *Poa*, according to Muntzing (15, 16), Tinney (25), Tinney and Aamodt (26), and Myers (17). Esau (8) from embryological studies came to the conclusion that in conjunction with the generative apospory unreduced pseudogamy occurs in the apomictic types of guayule.

Also, the differences in degree of self-compatibility and self-incompatibility should be mentioned. The exact physiological explanation for this self-incompatibility as suggested by Jost (9), Sears (21), and as reviewed by Sansome and Philp (20) cannot be given from these studies; but it is evident that some form of incompatibility is involved since in all but a very few cases a predominating proportion of the pollen is viable.

The necessity in a plant breeding program of having a measure of the frequency of occurrence of plants arising from these different methods of reproduction is apparent. The method employed in these studies and depicted in Table 3 was found to be entirely satisfactory. It should be pointed out that the most essential procedures of this method are the growing of both self-pollinated and cross-pollinated progenies from the same plant and following this practice for all plants involved in the reciprocal cross-pollinations. By following the methods depicted by Table 3, an estimate can be obtained of the frequency of occurrence of plants arising from the different methods of reproduction together with a measure of the effectiveness in producing viable seed of pollen possessing different genotypes. This method for determining the frequency of occurrence of plants arising from the different methods of reproduction and of measuring the degree of self- and cross-compatibility has proved satisfactory. In such studies when it is not possible or desirable to use plants or strains having distinct and easily classifiable genetic and phenotypic differences, an additional progeny test may be necessary to assure correct genotypic classification.

LITERATURE CITED

1. BERGNER, A. D. Guayule plants with low chromosome numbers. Science, 99: 224–225. 1944.
2. CRANE, M. B. Studies in relation to sterility in plums, cherries, apples and raspberries. Mem. Hort. Soc. New York, 3:119–134. 1927.
3. ————, AND LAWRENCE, W. J. C. Genetical and cytological aspects of incompatibility and sterility in cultivated fruits. Jour. Pomol. and Hort. Sci., 7:276–301. 1929.
4. ————, ————. Sterility and incompatibility in diploid and polyploid fruits. Jour. Gen., 24:97–107. 1931.
5. DIANOVA, V. I., SOSNOVETZ, A. A., AND STESHINA, N. A. Sravnitel ' noe tsito-embriologischeskoe issledovanie raznovidnostei *Parthenium argentatum* Gray i *Parthenium incanum*, Gray. Jour. de Bot. de l' URSS, 19 (5):447–466. 1934.
6. EAST, E. M., AND MANGELSDORF, A. J. Studies on self-sterility. VII. Heredity and selective pollen tube growth. Genetics, 11:466–481. 1926.
7. ————, AND YARNELL, S. H. Studies on self-sterility. Genetics, 14: 455–487. 1929.
8. ESAU, KATHERINE. Apomixis in guayule. (In Press).
9. JOST, L. Über Selbsterilitat einiger Blüten. Bot. Zeit., 65:77–117. 1907.
10. KALASHNIKOV, V. M. Materialy k metodike selektsii gvaiuly (*Parthenium argentatum*, Gray) Trudy po Prikladnoi Botanike Genetike, i Selektsii Bul. Appl. Bot., Gen., and Plant Breed., 27 (2):489–560. 1931.
11. KIRKWOOD, J. E. The life history of Parthenium (Guayule). Amer. Rev. Trop. Agr., 1 (7):193–205. 1910.
12. KOKIEVA, E. Morfologiia i istoriia razvitiia sotsvetii *Parthenium argentatum* G. (gvaiuly) i *Parthenium hysterophorus* L. Moskov. Obshch. Isp. Prirody, Otd. Biol. Bul., 40 (3/4):205–236, 375–383. 1931.
13. ————. Istoriia raz'itiia zhenskogo u *Parthenium argentatum* G. (guayule). Jour. de Bot. de l ' URSS, 17 (1) :72–99. 1932.
14. LLOYD, F. E. Guayule (*Parthenium argentatum* Gray). A rubber plant of the Chihuahuan desert. Carnegie Inst. Wash. Pub. No. 139. 1911.
15. MUNTZING, ARNE. Apomictic and sexual seed formation in *Poa*. Hereditas, 17:131–154. 1932.
16. ————. Further studies on apomixis and sexuality in *Poa*. Hereditas, 26:115–190. 1940.
17. MYERS, W. M. Second generation progeny tests of the method of reproduction in Kentucky bluegrass. Jour. Amer. Soc. Agron., 35:413–419. 1943.
18. PISSAREV, V. E. Selektsiia i priemy kul'tury gvaiuly. Trudy po Prikladnoi Botanike Genetike, i Selektsii, 24 (3):3–84. 1930.
19. ROLLINS, REED C. Evidence for natural hybridity between guayule (*Parthenium argentatum*) and mariola (*Parthenium incanum*). Amer. Jour. Bot., 31:93–99. 1944.
20. SANSOME, F. W., AND PHILP, J. Recent Advances in Plant Genetics. Philadelphia: P. Blakiston's, Son and Co., Inc. 1939.
21. SEARS, E. R. Cytological phenomena connected with self fertility in the flowering plants. Genetics, 22:130–181. 1937.
22. SHARP, L. W. Introduction to cytology. New York: McGraw-Hill Book Co. 1934.
23. STEBBINS, G. L. Apomixis in the angiosperms. Bot. Rev., 7:507–542. 1941.
24. ————. Chromosomal variation in guayule and mariola. Jour. Heredity, 35:163–172. 1944.
25. TINNEY, FRED W. Cytology of parthenogenesis in *Poa pratensis*. Jour. Agr. Res., 60:351–360. 1940.
26. ————, AND AAMODT, O. S. The progeny test as a measure of the types of seed-development in *Poa pratensis* L. Jour. Heredity, 31:457-464. 1940.

MALVACEOUS BAST FIBER STUDIES[1]

D. R. Ergle, B. B. Robinson, and J. M. Dempsey[2]

THE purpose of the investigations reported in this paper was to obtain information and quantitative data on the field growth, fiber content, and quality, together with ease of processing, of three malvaceous plants to determine the possibilities of their domestic production for fiber in a time of national emergency. Although not grown commercially in this country, they are cultivated in the tropical and subtropical climes of some countries as a source of fiber which has been manufactured into sacks, twine, ropes, etc. (6, 7, 8, 9, 10).[3] As the character of fiber produced by the malvaceous plants is similar to jute fiber, many attempts have been made to use them as substitutes for jute. Available information indicates that the plants studied are among the most suitable fiber plants that have possibilities for domestic production in the southern states.

SEED SOURCES

Seed of *Hibiscus* from two sources and of *Urena lobata* L. from one source were used in the studies reported here. Seed of one strain of *H. cannabinus* L., U.S.D.A. P.I. 145650, was imported from El Salvador, C. A., under the designation "roselle" or *H. sabdariffa* var. *altissima*. Choussey (2) states the Salvadorian seed originated from importations from Netherlands East Indies or French Indo-China. Botanical studies of the seeds, flowers, calyces, and leaves indicated this strain to be not specifically different from *H. cannabinus* and probably not a variety of *H. sabdariffa*. The true *H. sabdariffa* var. *altissimus* Wester originated in West Africa and it is not possible to establish its identity at the present time. The variety grown in these studies under the name of *H. sabdariffa* var. *altissima* is probably not any variety of *H. sabdariffa* but, like the true *H. sabdariffa var. altissimus*, it produces a tall unbranched stem. For distinction in the discussion in this paper it will be referred to as var. "*altissima*". Seed of the second strain of *H. cannabinus*, P.I. 144727, was obtained from Brazil and produced plants that differed morphologically from the var. "*altissima*" in that the plants branched profusely. The term *H. cannabinus* will be used to designate this strain. Seed of *Urena lobata*, P.I. 145797, was an importation from Cuba.

EXPERIMENTAL PROCEDURES AND METHODS

FIELD CULTURE

The plants were grown in 1943 on an Orangeburg sandy clay soil, moderately acid in reaction, located near Atmore, Ala.

Land preparation and fertilization consisted in the turning under of a winter cover crop of blue lupine, *Lupinus augustifolius* L., on March 10, disking, applying basic slag at the rate of 800 pounds per acre April 1, and the application of a 6–8–4 analysis fertilizer at 1,000 pounds per acre just before planting.

---

[1]Published as joint contribution from the Division of Cotton and Other Fiber Crops and Diseases, Agricultural Research Administration, Bureau of Plant Industry, Soils, and Agricultural Engineering, U. S. Dept. of Agriculture, in cooperation with Newport Industries, Inc., Pensacola, Florida; the Alabama Agricultural Experiment Station; and the Alabama State Department of Corrections and Institutions. Received for publication June 30, 1944.

[2]Chemist; Senior Agronomist, Bureau of Plant Industry, Soils, and Agricultural Engineering, U. S. Dept. of Agriculture; and Manager, Fiber Division, Newport Industries, Inc., Atmore, Alabama, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 126.

After lightly disking in the fertilizer, the seedings were broadcast by means of a board attached below a 7-foot seed drill. Sowing was followed by smoothing with a drag and a cultipacker. Var. "*altissima*" was planted April 8, *H. cannabinus* April 22, and *Urena lobata* May 13. An acre of var. "*altissima*" was seeded at 80 pounds per acre; two 1/10 acre plots of *Urena lobata* using mechanically scarified seed at 25 and 50 pounds per acre; and 1/40 acre of *H. cannabinus* at 60 pounds per acre.

The stand of seedlings of *Urena lobata* seeded at 25 pounds per acre was not sufficiently dense to combat the competition of encroaching native vegetation; therefore, frequent weeding by hand was necessary on this plot during the first month of growth.

SAMPLING AND CHEMICAL DETERMINATION OF USABLE FIBER

Two methods of sampling for different studies were practiced. The plantings were first sampled periodically for fiber plant samples for laboratory analysis from which periodical growth and fiber data were obtained. This sampling was restricted to a small area of uniform growth representing average plant development.

The plant samples comprising 5 to 20 plants, depending on their size, cut 2 inches from the ground were transported immediately to the laboratory for physical measurements and the removal of the green, fibrous phloem and cortical tissues which for simplicity will be hereafter referred to as the crude bast. The following physical data were obtained: Weight per plant, height of stalk before and after removal of nonfibrous tips, maximum stalk diameter at base, percentage of leaves and stalk in the plant, percentage of crude bast in stalk, and percentage of moisture in leaves and stalk dried at 105° C. In the preparation of the plant into leaves and stalks, the tender less mature fibrous growing point together with any inflorescence were included in the leaf fraction.

The fibrous crude bast was separated from the woody portion of the stalk with ease and reasonable accuracy by passing the stems between two rubber squeeze rolls revolving under adjustable tension. A hand-operated clothes wringer met the requirements. After passing through the wringer, the crude bast could be stripped from the woody stem core by hand. Oven-dry weight of each separate part was determined and the crude bast was reserved for chemical purification.

A sample of 30 to 40 grams oven-dry crude bast was soaked overnight in tap water as a presoftening treatment, removed, and the excess water removed by draining for a few minutes, and then placed in a beaker containing 4% sodium hydroxide solution in the ratio of 40 parts by volume of solution to 1 part by weight of over-dry crude bast. The beaker was covered with a watch glass and the solution was boiled gently for 30 minutes with frequent stirring. The contents of the beaker were poured upon a sieve with 0.0098 inch, circular openings, and the residue washed with tap water to remove the alkali, bark, and soluble constituents from the fiber.

The fiber at this stage of treatment was practically free of bark, gum, excess alkali, and soluble constituents. It was practically in the shape of the original crude bast with respect to length of fibrous strands. Further purification of the fiber was effected by partial bleaching to remove some of the coloring matter. The bleaching treatment was effected by agitating the fiber for 1 minute at room temperature in 1,000 ml of water containing 0.5 parts of chlorine as sodium hypochlorite. The solution was made slightly acid with 5% acetic acid solution, stirred, and the fiber immediately removed and washed. The washed fiber was next agitated in about 1,000 ml of water containing a few crystals of dissolved sodium thiosulfate as an antichlor, removed, washed thoroughly, squeezed into a thin mat with the hands, and dried to constant weight at 105° C. The weight of the purified fiber was expressed as percentage fiber in (a) oven-dry crude bast, (b) oven-dry stalk, and (c) green plant.

This method, based upon many preliminary determinations, gave a relatively quick, reproducible index of the usable purified fiber in the plants. Changing the concentration of sodium hydroxide in the degumming solution did not greatly affect the amount of fiber isolated, although a small decrease was associated with increasing concentrations of sodium hydroxide. The effect of increasing concentrations of sodium hydroxide, the ratio of fiber to volume of solution and time of boiling remaining constant, is shown by representative data on var. "*altissima*"

in Table 1. Using concentrations of 1% and 2%, the removal of the bark was incomplete and necessitated more washing and scrubbing than when higher concentrations were employed. The use of a 4% solution of sodium hydroxide was found to be the minimum concentration that would give a maximum yield of clean fiber and reproducible quantitative results. Employing 4% sodium hydroxide in the manner described, it was found from many duplicate determinations that the average deviation from the mean was plus or minus 0.39%.

TABLE 1.—*Effect of varying concentrations of sodium hydroxide in the chemical determination of fiber.*

Crude bast oven-dry weight, grams	NaOH %	Purified fiber oven-dry weight, grams	Purified fiber in crude bast %	Average %
48.7	1	27.8	57.1	56.2
38.6	1	21.3	55.2	
44.0	2	24.4	55.5	54.5
40.8	2	21.8	53.4	
40.0	4	21.7	54.2	54.3
33.8	4	18.4	54.4	
40.0	8	21.3	53.2	53.5
37.7	8	20.3	53.8	
40.3	16	21.4	53.1	53.0
36.2	16	19.1	52.8	

SAMPLING AND PREPARATION BY BIOLOGICAL RETTING

The second method of sampling was to obtain large amounts of plant material that might be handled under field conditions by methods applicable to commercial farm practices. It was planned originally to harvest these large samples of plant material at different dates corresponding to preflowering, early flowering, and late flowering stages in development. However, because the plants failed to develop these morphological characteristics as first anticipated under existing seasonal conditions at Atmore, it was necessary to govern the time of harvesting by the age in days and rate of growth of the plants.

Areas measuring not less than 100 square feet were cut in duplicate at each harvesting date. Dates on which plants were harvested are shown in Table 2. After obtaining the green weights of plants, half of the plants of each plot were then spread for dew retting and the remaining plants were water retted.

Water or biological retting was conducted in a concrete tank 10 feet long, 4 feet wide, and 3 feet deep, located out of doors. The green plants to be retted were submerged horizontally in the tank filled with tap water and were allowed to remain until the fibrous bast separated from the woody portions of the stalks and the bark could be washed from the fiber. The time required to ret with water during the period June through October varied from 5 to 18 days. After retting, the stalks were spread upon a wire screen and thoroughly washed. Pressure washing with a garden hose removed the bark and the slimy products of bacterial action. After sun drying, the retted stalks were stored under shelter until processed.

In dew retting, the green plants were spread over the stubble of the harvested areas and allowed to remain there until the weather effected a partial separation of the fiber from the wood. The plants were turned frequently to hasten and to enhance uniform retting. The dew-retted stalks were free of leaves, colored brown to buff with grey and black spots, containing about 15% moisture, and the fibrous bast, easily separated at any place by puncturing and pulling slightly with the thumb nail, was taut. The strand of loosened fibers,

when given a gentle winding movement with the hand, shed the epidermis exposing the fibrous filaments. The time required for dew retting varied from 23 to 39 days.

TABLE 2.—*Yields per acre of fiber plants harvested at different ages and processed differently.*

Seeding rate, lbs. per acre	Date harvested	Age, days	Average height, inches	Average diameter of stalk at base, mm	Green weight of plants, lbs.	Oven-dry weight of stalks, lbs.	Fiber extracted in lbs.	
							Chemically oven-dry	Mechanically air-dry
				H. cannabinus				
60	July 12	73	69	9	39,457	3,958	714	923
60	Aug. 7	98	109	15	73,454	10,657	1,728	—
60	Sept. 9	133	137	17	83,420	18,353	2,578	3,103
				Var. "*altissima*"				
80	June 22	71	55	9	26,157	3,280	987	1,067
80	July 28	107	101	13	54,140	9,236	1,933	2,469
80	Aug. 31	141	116	15	38,998	10,454	2,036	2,343
80	Oct. 23	194	125	15	37,375	10,787	2,078	2,791†
				Urena lobata				
25	Aug. 16	83	60	7	27,911	4,632	754	1,061
25	Sept. 1	101	62	9	25,427*	6,321	933	1,383
25	Oct. 6	135	69	10	31,266	7,635	1,063	1,482†
50	Aug. 16	83	52	6	35,105	6,000	1,004	1,334
50	Sept. 1	101	55	8	27,959*	6,603	1,060	1,521
50	Oct. 6	135	61	9	36,240	9,738	1,446	2,016

*Severe leaf injury by grasshoppers.
†Dew retted.

MECHANICAL EXTRACTION OF FIBERS

The fibers from dew- and water-retted plants were cleaned or prepared in an experimental fiber mill. This mill, commercial in size, was equipped essentially with machinery similar to that used for the commercial processing of hemp excluding a scutcher. Therefore a mixture of both line and tow was produced from the stalks processed. In processing, the stalks were dried down to approximately 2 to 4% moisture by passage for 90 minutes through a dryer having a maximum temperature of 95° C. The dried stalks were then broken by passage through a series of pairs of fluted rolls followed by a bar beater. The shives or hurds were removed by a series of three inclined slat shakers equipped with two sets of kickers. The partially cleaned fiber was cleaned further through a series of pairs of finely fluted iron rolls followed by a bar beater.

INDEX OF TENSILE STRENGTH

Breaking strength tests of fibers were made with a Scott yarn tester using spool clamps. The sample tested comprised fiber strands 25 centimeters in length, 0.2 to 0.7 gram in weight, and conditioned at 66% humidity. The breaking distance between centers of clamps was 7.5 cm. Ten tests were made on each lot of fiber and the results expressed as kilograms breaking strength per gram of fiber 25 cm long. These tests were made by Dr. L. E. Hessler, University of Kentucky, Lexington, Ky.

RESULTS AND DISCUSSION

GROWTH AND PLANT COMPOSITION

Periodic data on growth and composition of *H. cannabinus*, var. "*altissima*", and *Urena lobata* (50-pound seeding rate) are tabulated in Tables 3, 4, and 5. Seed of *H. cannabinus*, var. "*altissima*", and *Urena lobata* germinated in 8, 5, and 5 days, respectively, giving a good stand of plants in all plots. Plant height in the plot of *H. cannabinus* was not as uniform as in the plots of the other fiber plants due to unequal rate of seed germination. Based upon height, weight, and stalk diameter at base, reference to growth data in Tables 2, 3, 4, and 5 shows that plant size was in the decreasing order of *H. cannabinus*, var. "*altissima*", and *Urena lobata*. On October 25 the number of plants per square foot of soil was for *H. cannabinus*, 3.30; for var. "*altissima*", 4.75; and for *Urena lobata* at a 25-pound seeding rate, 5.56, and at a 50-pound seeding rate, 12.20. Some of the plants counted in the plot of the higher seeding rate were practically too small for fiber use. However, it is believed their presence was beneficial in combating native vegetation and in the production of other stalks better suited for fiber than those produced under the conditions of the 25-pound seeding rate. Illustrations of the type of growth obtained with var. "*altissima*" and *Urena lobata* are shown in Figs. 1 and 2.

The maximum growth of *Urena lobata* probably was curtailed somewhat by an infestation of grasshoppers which destroyed a high percentage of the leaves. The grasshoppers did not molest the plantings of *H. cannabinus* and var. "*altissima*" despite their proximity to the plots of *Urena lobata*. However, the field culture of var. "*altissima*" at the end of the season was attended with a severe infestation of several species of nematodes. The yield of neither plants nor fiber was noticeably affected as plant growth had ceased and harvesting studies had terminated. Some of the infected plants were killed, but the majority of the plants remained alive until killed by frosts. An examination of the roots of *H. cannabinus* and *Urena lobata* failed to reveal any signs of nematode infection.

H. cannabinus and var. "*altissima*", age 176 and 194 days, respectively, did not start blooming until October 23 after the latter had shed the major portion of its leaves. *Urena lobata* did not produce any inflorescence up to the time all the fiber plants were killed by frost in November. Var. "*altissima*", planted on August 7, 1942, in the same location, commenced blooming October 21 at the age of 55 days of growth. However, neither in 1942 nor 1943 did var. "*altissima*" or *H. cannabinus* mature seed before killed by frost. The delay in flowering of var. "*altissima*" regardless of plant age until the latter part of October confirms results of Bolhuis (1) that the length of day influences the flowering of these plants.

In all three plants the percentage leaves and the percentage moisture in leaves and stalks decreased fairly consistently during plant growth and development. At the same time the stalk content was increasing, with its component parts of crude bast decreasing and the shives increasing. The fairly consistent decrease in concentration

TABLE 3.—*Changes in fiber content and nonfibrous components of Hibiscus cannabinus associated with advancing age.*

Date, 1943	Age, days	Average height, inches	Average fresh weight per plant, grams	Stalk, green weight basis %	Moisture in		Crude bast in stalk, oven-dry basis %	Percentage purified fiber in		
					Leaves, green weight basis %	Stalk, green weight basis %		Crude bast, oven-dry basis	Stalk, oven-dry basis	Whole plant, green weight basis
June 5...	36	25.6	59.4	29.8	81.2	80.6	45.3	30.4	13.8	0.8
June 14..	45	33.4	67.1	36.2	84.5	82.7	45.9	36.7	16.9	1.1
June 21..	52	43.8	96.4	40.3	84.5	81.0	44.5	39.4	17.5	1.4
July 1....	62	57.1	165.0	44.0	86.1	82.7	44.2	41.6	18.4	1.4
July 8....	69	69.0	203.0	49.9	85.0	79.9	41.5	43.6	18.1	1.8
July 19...	80	74.8	211.0	53.6	84.9	78.1	40.1	44.3	17.7	2.1
July 26...	87	92.4	252.0	59.3	82.0	74.6	38.7	45.0	17.4	2.6
Aug. 6...	98	109.0	456.0	58.5	83.9	75.2	35.3	46.0	16.2	2.4
Aug. 19..	111	124.0	419.0	63.9	83.1	73.0	34.4	48.8	16.8	2.9
Aug. 28..	120	123.0	408.0	67.6	81.5	73.6	37.9	48.8	18.5	3.1
Sept. 10..	133	137.0	503.0	71.2	80.4	69.1	30.2	46.3	14.0	3.1
Oct. 5....	158	134.0	464.0	68.3	82.3	66.8	29.4	43.6	12.8	2.9
Oct. 25...	178	144.0	418.0	80.0	—	—	—*	—*	—*	—*

*Bast clinging too tightly for quantitative removal.

TABLE 4.—*Changes in fiber content and nonfibrous components of var. "altissima" associated with advancing age.*

Date, 1943	Age, days	Average height, inches	Average fresh weight per plant, grams	Stalk, green weight basis %	Moisture in		Crude bast in stalk, oven-dry basis %	Percentage purified fiber in		
					Leaves, green weight basis %	Stalk, green weight basis %		Crude bast, oven-dry basis	Stalk, oven-dry basis	Whole plant, green weight basis
May 27..	45	28.0	53.8	39.0	87.3	88.7	46.2	32.8	15.2	0.7
June 4...	53	39.6	55.3	54.2	83.4	83.0	42.8	38.5	16.5	1.5
June 12..	61	51.3	64.0	65.0	82.2	81.0	43.7	45.5	19.8	2.5
June 19..	68	54.9	74.9	62.7	82.1	80.0	42.1	45.6	19.2	2.3
June 26..	75	64.4	102.0	69.1	82.7	81.5	40.5	50.1	20.4	2.6
July 8....	87	74.2	154.0	66.6	83.6	80.4	41.8	46.2	19.3	2.5
July 19..	98	81.2	163.0	68.3	83.8	81.0	43.2	52.4	22.7	2.9
July 28...	107	101.0	255.0	72.9	82.4	76.6	40.9	51.2	21.0	3.6
Aug. 19..	129	107.0	233.0	81.6	80.3	72.7	40.2	53.8	21.5	4.8
Sept. 10..	151	116.0	242.0	82.7	81.0	70.8	38.9	55.1	21.4	5.2
Sept. 17..	158	119.0	258.0	81.7	81.1	70.2	38.6	57.6	22.2	5.5
Oct. 6....	177	120.0	252.0	83.9	80.8	69.8	37.5	55.0	20.7	5.2
Oct. 23...	194	125.0	271.0	85.2	80.0	67.7	32.9	54.0	17.8	4.9

TABLE 5.—*Changes in fiber content and nonfibrous components of Urena lobata associated with advancing age.*

Date, 1943	Age, days	Average height, inches	Average fresh weight per plant, grams	Stalk, green weight basis %	Moisture in		Crude bast in stalk, oven-dry basis %	Percentage purified fiber in		
					Leaves, green weight basis %	Stalk, green weight basis %		Crude bast, oven-dry basis	Stalk, oven-dry basis	Whole plant, green weight basis
June 30..	38	21.7	12.1	37.7	80.6	83.9	47.3	30.3	14.3	0.9
July 9....	47	30.8	17.0	55.4	75.8	80.6	45.0	34.0	14.3	1.6
July 17...	55	36.4	28.7	53.0	78.1	80.6	42.2	42.4	17.9	1.8
July 24...	62	43.4	34.7	66.7	69.7	75.5	41.2	41.6	17.1	2.8
Aug. 5...	74	49.9	50.6	59.1	75.6	77.2	41.5	40.6	16.8	2.3
Aug. 14..	83	52.3	51.7	65.4	73.5	73.5	39.3	42.6	16.7	2.9
Aug. 27..	96	58.1	51.5	78.2	66.3	69.8	37.9	42.3	16.0	3.8
Sept. 10..	110	58.9	60.0	80.4	60.4	64.2	37.0	42.5	15.7	4.5
Sept. 21..	121	59.6	48.9	79.3	71.0	67.2	43.8	34.4	15.1	3.9
Oct. 5....	135	61.4	51.5	78.8	66.0	65.9	35.7	41.7	14.9	4.0
Nov. 3...	164	63.8	54.7	85.6	64.4	59.5	33.2	38.4	12.8	4.4

FIG. 1.—Var. "*altissima*", 158 days old; height, 119 inches; purified fiber content of green plant, 5.5%.

of crude bast in the stalk during growth was accompanied by an increasing concentration of pure fiber in the crude bast. That is, the nonfibrous materials decreased while at the same time the fiber in the crude bast was increasing.

In terms of percentage concentration in the oven-dry stalks, the trend of the purified fiber of var. "*altissima*" was upward during the first 98 days of growth and then remained near a maximum until 158 days old after which it decreased slightly during the remainder of the season. In *H. cannabinus* the trend was uninterruptedly upward in the first 62 days, followed then by a decrease in concentration that became more marked after 120 days old. *Urena lobata*

FIG. 2.—*Urena lobata*, 135 days old; height, 64 inches; purified fiber content of green plant, 4.0%.

reached a maximum concentration of fiber in the stalk after 55 days of growth and then consistently decreased during the remainder of its growth period.

YIELDS

As shown by yields data in Table 2, *H. cannabinus* produced a maximum of 83,420 pounds of green plants per acre at the last date of harvest; var. "*altissima*" was next in order with a maximum yield of 54,140 pounds at the second date of harvest; *Urena lobata*, 50-pound seeding rate, 36,240 pounds at the last date of harvest; and the 25-pound seeding rate 31,266 pounds at the last date of harvest. Due to natural leaf shedding in the case of var. "*altissima*" and natural shedding plus leaf injury from grasshoppers in the case of *Urena lobata*, the yield data on green plants did not increase consistently with age. Expressed as pounds per acre of oven-dry stalks, the yields of species consistently increased with advancing age during the period of study. The 50-pound seeding rate of *Urena lobata* produced stalks of smaller diameter and height but of a slightly higher concentration of fiber than did the 25-pound seeding rate.

The calculated fiber yields based upon methods of chemical and mechanical extraction are compared in Table 2. In general, the maximum yields of both purified and mechanically extracted fibers were obtained at the third harvest. The maximum amounts of processed fiber produced by the three fiber plants, in pounds per acre, are as follows: *H. cannabinus*, 3,103; var. "*altissima*", 2,791; and *Urena lobata* at the 25-pound seeding rate, 1,482, and at the 50-pound seeding rate, 2,016. These yields compare favorably with some yields obtained in countries where these plants are grown for commercial fiber production. From a survey of the literature, Crane (3) found that reported yields of *H. cannabinus* fiber in India, Egypt, Java, Senegal, Nigeria, and Rhodesia varied from 1,000 to 6,245 pounds per acre. Choussy (2) gives some yields on fiber from var. "*altissima*" grown in Buitenzorg, Java which varied from 500 to 3,000 kilograms per hectare (446 to 2,677 pounds per acre) for plants 75 up to 165 days old, respectively. De Groof (4) states that *Urena lobata* fiber yields in the Belgian Congo are variable but good yields are 800 to 1,000 kilograms (1,764 to 2,205 pounds) per acre. Some yields of double this amount have been obtained.

Reference to Table 2 will show that the yields of mechanically processed fibers exceeded by 8.1 to 48.2% the yields of purified fibers. There is justification for believing that the theoretical yield of mechanically processed fiber would be higher than that reported if the loss of a certain amount of short fiber not retained by the slat shakers in cleaning were recovered. From a practical standpoint, however, this short fiber would be of little value. The purpose of determining the fiber chemically was to follow as accurately as possible the changes in pure fiber in relation to growth of the plant. The fiber determined by retting and processing in the fiber mill simulated commercial methods and the yields thus obtained are indicative of the productivity of the fiber plants under the conditions of experimentation described. However, some of the superiority in fiber yields by mechanical

processing was due to the presence of moisture and some unavoidable contamination from wood and bark, all of which were absent from the purified fiber. Hypothetically, the source of greatest variance was in the removal during chemical degumming of certain materials which were either not removed or to a less degree in biological retting. The extent to which such substances were removed and their identification were not within the scope of the investigations reported.

RETTING

There was not any noticeable variation in rate of retting among the three plants studied, for the various plant lots water retted without additional heat. The possibility that differences in retting time associated with species and plant age may have existed is admitted, but it is reasonable to assume that such differences might easily have been obscured by changes in temperature and other interrelated factors not controlled. Var. "*altissima*", *H. cannabinus*, and *Urena lobata* retted in 6 to 8 days during June, July, and August but required about 18 days in September and October. The increase in retting time was due principally to prevailing lower temperatures. Comparative warm water retting tests conducted in the laboratory on small amounts of green basts at a constant temperature of 32°C gave the following results: var. "*altissima*" retted in 10 days, *H. cannabinus* in 8 days, and *Urena lobata* in 7 days.

In the dew retting tests, the fiber plants retted to some extent, but the results were different from those that usually occur in the retting of such plants as hemp and flax. The fiber, instead of being grey in color and relatively soft, was tan to straw in color and harsh. Some response to dew retting was evidenced by loosening of the fiber bast, separation of the fiber into strands when the bast was rubbed between the fingers, and the production of a clean fiber when decorticated. Retting of the type obtained occurred within 23 to 39 days regardless of plant species, age of plant, or time of year when the retting was conducted. Longer exposures to the weather elements were increasingly detrimental to fiber strength index. Observational data suggested that stalk diameter was influential in the time required for dew retting. Using the results from var. "*altissima*" as typically illustrative, stalks of 12-mm butt diameter and less retted in 23 to 27 days, while those of larger diameter required 33 to 39 days.

MECHANICAL PROCESSING

The mechanical processing of the fibers, water and dew retted, was accomplished without any major difficulty and produced a clean fiber. A possible impairment in fiber strength due to processing is indicated by limited and inclusive data in Table 6. Fiber samples of *H. cannabinus* and *Urena lobata*, with breaking strength values of 68.6 and 116.7, respectively, were separated by hand from retted, air-dry stalks. The magnitude of the difference between these values and comparable ones given in the same table for mechanically decorticated fiber seems significant. Predrying of the stalks at 95°C prior to decortication may have increased the brittleness of the fiber

to a critical point. Serious damage to *H. cannabinus* during mechanical extraction has been observed by Dekker (5).

TABLE 6.—*Breaking strength of processed fibers.*

Harvest	Method of preparation	Breaking strength	
		K/g*	P.E.
	Hibiscus cannabinus		
1	Water retted	47.0	±1.12
3	Water retted	29.9	±1.11
3	Dew retted	68.6†	±3.37
	Var. "*altissima*"		
1	Water retted	86.2	±1.79
2	Water retted	62.3	±1.33
3	Water retted	66.0	±0.64
2	Dew retted	44.5	±0.61
4	Dew retted 23 days	51.6	±2.70
4	Dew retted 39 days	31.4	±1.79
	Urena lobata		
1	Water retted	57.2	±1.45
2	Water retted	42.7	±1.96
3	Water retted	62.6	±2.63
3	Water retted	116.7†	±1.46
2	Dew retted	39.5	±2.04
3	Dew retted	32.3	±2.19

*Kilograms breaking strength per gram fiber 25 cm long.
†Fiber separated by hand.

Of the three fibers studied, var. "*altissima*" from both dew- and water-retted stalks broke out with the greatest ease and cleanliness. This was thought to be due to the fragility and lightness of the woody tissue of the stalks, a distinguishing property. The wood in *H. cannabinus* and *Urena lobata* was considerably denser and in the case of the former the stalks of large diameter from the third harvest offered considerable resistance to the action of the breakers in the mill. This resistance to decortication is believed to be partly responsible for the low breaking strength of *H. cannabinus* fiber as shown in Table 6. The stalk diameter of *Urena lobata* was not large and the retted stalks were decorticated without any similar detriment to its fiber.

FIBER PROPERTIES

Preparation of the fiber plants for fiber extraction by water retting gave the best quality of fiber. The fiber was comparatively soft, lustrous creamy white to grey-white in color, long, and comparatively strong. The dew-retted fiber was harsh, brittle, shorter, weaker, and tan to straw in color. The strength of the water-retted fibers and those dew retted are shown by breaking strength data assembled in Table 6.

As might be expected the quality of the three fibers with respect to breaking strength, color, and texture was found to vary somewhat

with the time of plant harvest. As indicated by breaking strength data in Table 6, var. "*altissima*" 71 days old (harvest 1) had the best strength; *H. cannabinus* 73 days old (harvest 1) and *Urena lobata* 135 days old (harvest 3) exhibited best strengths. However, it is believed that the data are of limited value in attempting to establish a relationship between fiber strength and plant age or in rating the relative strength of the three fibers. This phase of the work requires special study. Without any outstanding differences between the species, the fiber from plants of the last date of harvest had lost some of the creamy white color observed in the fiber from plants of the first two dates of harvest and was replaced by a silver-grey color. Observational evidence indicated that fiber strands from plants of the third harvest were coarser in texture than strands from plants of earlier harvests. This was true particularly of the fiber from the lower portion of the stalk. In this respect, changes in *Urena lobata* fiber were less noticeable than with fiber from var. "*altissima*" and *H. cannabinus* which was produced by stalks of larger diameter.

Samples of the fibers prepared by water retting and mechanical processing were submitted to some American fiber maunfacturers for their evaluation. The quality of the fibers was considered favorable from the standpoint of their utilization as a substitute for jute.

SUMMARY AND CONCLUSIONS

Three malvaceous bast fiber plants, *Hibiscus cannabinus* L., *H. sabdariffa* var. *altissima*, and *Urena Lobata* L. were grown experimentally near Altmore, Ala., and studied from the standpoint of possible utilization as sources of bast fiber in time of a national emergency. The environmental requirements, climatic and edaphic, for growth seemed adequate. However, these or other factors were not suitable for the maturation of seed. Flowering either occurred late or not at all during the period of growth. The delay in flowering until late in October confirms other investigations in reference to the influence of photoperiodism.

Maximum yields in pounds per acre of mill-run fiber produced under the experimental conditions described were as follows: *H. cannabinus*, 3,103; var. "*altissima*", 2,791; *Urena lobata* at the 25-pound seeding rate, 1,482, and at 50-pound seeding rate, 2,016. By comparison with yields reported in some countries where these plants are grown commercially, the yields given here may be considered good.

A chemical method of extraction was developed and used to follow the changes in pure fiber content of the plants throughout their growth cycle. It gave lower but consistent and reproducible results as compared to the results obtained by biological retting and subsequent mechanical extraction.

A study of the progress of fiber formation during the growth and development of the plants showed somewhat similar increases in the fiber content during early growth and decrease in extractable fiber content near maturity.

The results from retting tests showed that the fibers from water-retted plants were superior in strength and quality to the fibers from dew-retted plants. Retting with water was accomplished in 6 to 18 days depending on the temperature of the water in the retting tank. To ret with dew required 23 to 27 days for stalks of small diameter and up to 39 days for large stalks.

Mechanical extraction of the fibers in a hemp-tow fiber mill was investigated. The stalks of var. "*altissima*" and *Urena lobata* were easily decorticated and yielded a relatively clean fiber. Many of the stalks from the late harvest of *H. cannabinus* were too large and too dense and did not give as clean and strong a fiber as stalks from earlier harvests.

Under conditions of experimentation, the fibers of var. "*altissima*" and *Urena lobata* were superior in strength to that of *H. cannabinus*. Based upon the experimental data and information obtained, it would appear that the results on growth, fiber yields, mechanical processing, and fiber quality justify consideration of these malvaceous species as a domestic source of jute-like fiber if needed.

LITERATURE CITED

1. Bolhuis, G. G. Bloeiwaarnemingen bij *Hibiscus sabdariffa* L. en *Hibiscus cannabinus* L. Landbouw, 16:404–412. 1940.
2. Choussy, Felix. El posible implantamiento del cultivo de la Rosella en El Salvador. Talleres Graficos Cisneros, San Salvador. 1942.
3. Crane, Julian C. Kenaf (*Hibiscus cannabinus* L.) as a fiber crop. Mimeograph Pub. of U. S. D. A. Office of Foreign Agr. Relations, Div. of Latin American Agriculture, 22, 1943.
4. De Groof, G. La culture et l'exploitation des plantes a filasse dans la province de Leopoldville. Bul. Agr. Congo Belge, 27:548–577. 1936.
5. Dekker, J. F. Java-jute en roselle. Landbouw, 9:507–513. 1934.
6. Dewey, Lyster H. Fiber Production in the Western Hemisphere. U. S. D. A., Misc. Pub. No. 518. 1943.
7. Dodge, Charles Richards. A report on the uncultivated bast fibers of the United States. U. S. D. A. Report No. 6. 1894.
8. Frenzel, W., and Bruggencate, A. Ten. Spin-en weefproeven met rosellevezel van Java. (Netherlands) Rijksvoorlichtingsdienst ten Behoeve Vezelhandel en Vezelnijverheid. Meded., 22. 1929. (Abstract in Biol. Abs., 5:1769–1770. 1931.)
9. Oudot, G. Plantes a fibres I–III. Bul. Econ. de l'Indochine, 43:77–91. 1940.
10. Pan American News. Brazilian bag factory using native fibers. Bulletin of Pan American Union. 1941.

WHEAT BUNT FIELD TRIALS[1]

George A. Baker and Fred N. Briggs[2]

IN THE study of inheritance of resistance to bunt, *Tilletia tritici*, in wheat it is necessary to grow F_3 progenies from F_2 plants in order to determine the genotype of the latter. This is necessary because all susceptible plants in a population usually do not show the disease under conditions generally prevailing. Such plants merely escape infection and do not differ genetically from those which exhibit it. The situation is further complicated by the fact that some heterozygous resistant and occasionally some homozygous resistant plants become diseased.

Briggs (1, 2, 3)[3] has shown that there is little difficulty in distinguishing the three genotypes in crosses where the parents differ by a single factor if F_3 rows of about 50 plants each are grown, although in most crosses there were a few rows which could not be positively classified. Both heterozygous rows and susceptible rows usually exhibit a range of about 50%. Where parents differ by two (1) or more factors for resistance, the overlapping of rows belonging to the several genotypes makes it difficult if not impossible to recognize the rows belonging to the various genotypes, thus genetical analysis may be very unsatisfactory.

The question arose as to whether the range in bunt infection among rows of a given genotype could be accounted for on the basis of sampling error and if the variability would decrease according to expectations as the number of plants per row increased. A decrease in variability would indicate the limits of the three genotypes more certainly in the case of a single factor difference. If the decrease was sufficient it would permit the recognition of the greater number of genotypes where more factors are involved. An alternative approach to analyzing the more complicated crosses would be to set up a theoretical distribution, using the necessary factors with the proper effects to fit the observed distribution of rows. In order to set up such a theoretical distribution, it is necessary to properly evaluate the errors for each genotype.

Salmon (4) has shown that the sampling error will not account for the variation in bunt infection among wheat varieties. He found it necessary to increase this error by *a*, which varied for different environmental conditions and levels of infection.

By using an F_3 population of about 340 plants, Stanford (5) was able to make a satisfactory genetical analysis of a cross between Rio and Baart wheats which had not been possible where only 50 plants were grown.

MATERIALS AND METHODS

The cross between Banner Berkeley and Baart was made in 1934 for the

[1]Contribution from the Division of Agronomy, California Agricultural Experiment Station, Davis, Calif. Received for publication August 25, 1944.
[2]Assistant Statistician and Professor of Agronomy, respectively.
[3]Figures in parenthesis refer to "Literature Cited", p. 133.

purpose of this study and the F_3 rows were grown in 1937. Banner Berkeley was known to differ from Baart in one dominant factor for resistance (2). Three rod rows of approximately 50 plants each were grown from 224 F_2 plants. These rows were planted adjacent to each other in order to grow each family under as uniform conditions as possible. By using one, two, and three rows, populations of 50, 100, and 150 plants were available for study. A number of F_2 and parent rows were included.

The methods of handling and the source of inoculation were the same as previously described by Briggs (3). In order to have as nearly as possible the same number of plants per row, 80 seeds were planted in each row.

EXPERIMENTAL RESULTS

The percentages of bunt for the single rows of the parents and F_2 and for one, two, and three F_3 rows are given in Table 1, and shown graphically in Fig. 1.

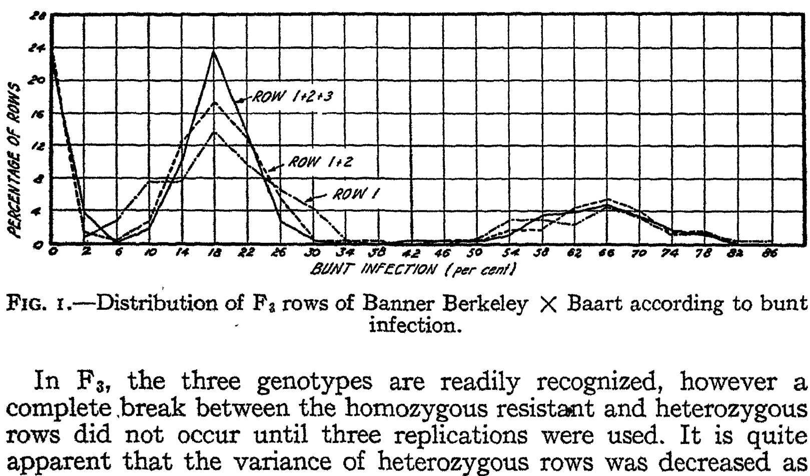

FIG. 1.—Distribution of F_3 rows of Banner Berkeley × Baart according to bunt infection.

In F_3, the three genotypes are readily recognized, however a complete break between the homozygous resistant and heterozygous rows did not occur until three replications were used. It is quite apparent that the variance of heterozygous rows was decreased as the number of plants per row was increased. However, little decrease resulted in the susceptible group.

A detailed comparison of the means and standard errors for the various groups may be seen in Table 2. Baart had an average of 65.54% of bunt and the susceptible F_3 rows had 64.92, 64.33, and 64.42% for rows 1, 1 + 2, and 1 + 2 + 3, respectively. The agreement between the F_2 and the heterozygous F_3 rows was not so good. The former had 15.77% compared with 18.58, 18.51, and 18.44% for F_3 in rows 1, 1 + 2, and 1 + 2 + 3. The above results indicate, however, that the overall conditions for bunt infection were fairly uniform.

In comparing the actual standard error (S_1) with the sampling standard error (S_2) it will be noted that the actual error is greater than the sampling error in every case. This indicates, as Salmon (5) found, that the environment is contributing to the total variance. The S_1/S_2 ratio for Baart agrees very well with the ratio of susceptible F_3 rows where all three rows are used, but is somewhat higher than those for rows 1, and 1 + 2. All these ratios in turn are higher than those for segregating rows. Since the overall environ-

Parent or cross	Generation	Row	Percentage classes 0–4: 0	0–4: 1–4	4–8	8–12	12–16	16–20	20–24	24–28	28–32	32–36	36–40	40–44	44–48	48–52	52–56	56–60	60–64	64–68	68–72	72–76	76–80	80–84	84–88	Total number of rows
Banner Berkeley...	P	—	16	3	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Baart...........	P	—	—	—	—	—	—	—	—	—	—	—	1	2	2	2	3	3	7	7	3	7	2	6	0	44
Banner Berkeley × Baart.........	F_2	—	—	—	5	8	15	14	4	2	0	1	0	1	—	—	—	—	—	—	—	—	—	—	—	50
Banner Berkeley × Baart.........	F_3	1	56	2	6	16	17	32	23	14	9	1	0	1	0	2	7	7	5	11	7	3	4	0	1	224
Banner Berkeley × Baart.........	F_3	1+2	56	3	1	7	28	38	29	12	1	1	0	0	2	1	4	4	10	12	9	3	3	0	0	224
Banner Berkeley × Baart...... ...	F_3	1+2+3	51	8	0	5	22	54	29	6	1	0	0	0	2	1	2	7	10	11	8	4	3	0	0	224

TABLE 2.—*Comparison of actual, binomial, and calculated standard error of percentage bunt infection for different length rows for the hybrids of Banner Berkeley × Baart.*

Parent or hybrid	Generation	F_2 genotype	Row	Number of plots	Mean % smutted plants	Number plants per plot	Standard error: Actual (S_1)	Standard error: $\sqrt{\frac{pq}{n}} = S_2$	$\frac{S_1}{S_2}$	S. E. calculated (Σ)*
Baart..................	P	—	—	44	64.54	57.7	11.63	6.30	1.85	—
Banner Berkeley × Baart	F_2	—	—	50	15.77	55.7	6.46	4.88	1.32	—
Banner Berkeley × Baart	F_3	bb	1	48	64.92	50	8.84	6.75	1.31	10.80
Banner Berkeley × Baart	F_3	bb	1+2	48	64.33	100	7.48	4.79	1.56	7.66
Banner Berkeley × Baart	F_3	bb	1+2+3	48	64.42	150	7.44	3.91	1.90	6.26
Banner Berkeley × Baart	F_3	Bb	1	117	18.58	50	6.36	5.50	1.13	6.49
Banner Berkeley × Baart	F_3	Bb	1+2	117	18.51	100	4.75	3.88	1.19	4.34
Banner Berkeley × Baart	F_3	Bb	1+2+3	117	18.41	150	3.75	3.19	1.18	3.74

*Calculated from equation (6), using a's = 1.6 and Rij = 1 for the heterozygous rows and by multiplying S_2 by 1.6 for the susceptible rows.

mental factors appear to be quite uniform as reflected by the mean percentages of bunt, it was thought at first that the S_1/S_2 ratios for the rows arising from the various genotypes should be similar and in turn should be of the same order of magnitude as that for Baart. This seeming paradox may be solved by comparing the variabilities of the various populations.

THEORETICAL RESULTS

We will assume first that a row of n plants is homogeneous with respect to the probability of infection as would be the case in a susceptible variety or homozygous susceptible hybrid population. Let p_i be the probability of infection in the i^{th} row of which there are N and put

$$\frac{1}{N}\sum_{i=1}^{N} p_i = p, \quad \frac{1}{N}\sum_{i=1}^{N} (p_i - p)^2 = V \qquad 1$$

Then for heterozygous rows in which only homozygous susceptible plants become infected, the mean proportion of infected plants and the variance of the proportions of infected plants are

$$M = p/4 \qquad 2$$

$$\Sigma^2 = \frac{p(4-p)}{16n} + \frac{(n-1)V}{16n}. \qquad 3$$

The ratio of observed variances of per cents or proportions infected to the corresponding binomial variance will be designated by a^2, which is an estimate of R^2, the ratio of 3 to the corresponding binomial variance $p(4-p)/16n$. If the experiment conforms to our assumptions,

$$R^2 = 1 + \frac{(n-1)V}{p(4-p)} \qquad 4$$

and hence is always greater than 1. R depends on three quantities n, V, and p. R tends to increase with the length of the row, i.e., with n, except that as the length of the row increases V tends to decrease. That is, V is probably a function of n and R may be constant with respect to n.

We shall consider now that all three types of plants in the heterozygous row can be infected. In this case the formulas corresponding to 2 and 3 are

$$M = \tfrac{1}{4}(p_1 + 2p_2 + p_3) \qquad 5$$

and

$$\Sigma^2 = \frac{1}{16n}\Big[p_1(4-p_1) + 4p_2(2-p_2) + p_3(4-p_3)\Big] - \frac{1}{8n}(2p_1p_2 + p_1p_3 + 2p_2p_3) + \frac{(n-1)}{16n}(V_1 + 4V_2 + V_3) + \frac{(n-1)}{16n}\Big[2(V_1V_2)^{\frac{1}{2}}R_{12} + (V_1V_3)^{\frac{1}{2}}R_{13} + 2(V_2V_3)^{\frac{1}{2}}R_{23}\Big] \quad 6$$

where the p_i's and V_i's have the same significance for each of the three types of plants as p and V in 1 (the subscripts refer to susceptible, heterozygous and resistant in order) and the R_{ij}'s represent the correlation between the probabilities of infection for the various types of plants within the rows. The terms not involving the V_i's give the variance obtained from the binomial formula with $p = M$, i.e. S^2_2.

In 6 we may expect that the R's are positive and close to 1. That is, if the probability of infection in a row is high for one type of plant, then it will be high for the other types of plants also and *vice versa.* We shall assume, therefore, that $R_{12} = R_{13} = R_{23} = 1$.

The formulas 2, 3, 5, and 6 have been derived on the basis that each row is homogeneous with regard to probability of infection. This is not strictly true. Professor J. Neyman of the Department Mathematics, University of California, Berkeley, Calif., has given, in a letter, formulas which show that the effect of allowing for variation of probability of infection within rows is to decrease slightly Σ^2. If the variation within rows is equal to the variation between rows and the correlations within rows is equal to the correlations between rows, then $(n-1)$ is replaced by $(n-2)$ in 3 and 6. This correction is negligible with respect to other types of errors that are unavoidable in any experiment. Therefore, the formulas 3 and 6 with the R's = 1 will be used as given.

In many experiments we can observe the means and variances of the proportions of infected plants in the homozygously resistant, homozygously susceptible, and heterozygous rows. From these data and formulas 5 and 6 it is possible to compute p_2 and V_2. From V_2 we compute the more conventional a_2 since $(n-1)\ V_i = (a^2_i - 1)\ p_i\ (1-p_i)$, $i = 1, 2, 3$.

APPLICATION OF THEORY TO EXPERIMENTAL RESULTS

It would simplify things very much if it turned out that the same a applied to the different types of plants, i.e., $a_1 = a_2 = a_3$. If the a's were independent of n, the number of plants per row, this would also make the application much simpler.

From the Banner Berkeley data given in Table 2, we see that for replication 1, p_1 is 64.92. The heterozygous rows in the same series have a mean percentage of bunt of 18.58, which is 2.35% more than would be expected from the infection of susceptible plants, ¼p_1 in such a row and therefore must have resulted from the infection of

heterozygous plants. The p_3 must have been very near 0 as evidenced by the Banner Berkeley parent and the resistant rows. From the data we determine a's for n = 50, 100, and 150 that will give the observed variance of the heterozygous rows on the assumption that $a_1 = a_2$. We use the formula

$$a^2 - 1 = \frac{16n\,(\Sigma^2 - S_2^2)}{[p_1(1-p_1) + 4p_2(1-p_2) + \sqrt{p_1(1-p_1)\,4p_2(1-p_2)}]} \qquad 7$$

We find that a = 1.53 for n = 50, a = 1.71 for n = 100, a = 1.53 for n = 150 if Σ^2 is replaced by its estimates S^2_1. No definite trend is apparent and we assume that a has the simple average value of 1.6 independent of n. It is noted that the value 1.6 for *a* is consistent with the observed values of 1.31, 1.56, and 1.90 given in Table 2 for the susceptible "rows" with 50, 100, and 150 plants since none of these values give standard deviations that differ significantly from the values obtained by assuming a = 1.6.

Using a = 1.6 and computing standard deviations for the heterozygous rows, we obtain 6.49, 4.34, and 3.74 as compared to observed values of 6.36, 4.75, and 3.75, respectively. None of the observed values differ significantly from the corresponding computed values.

On the basis of this experiment it appears that *a* may be nearly constant for plants of a considerable variety of genotypes and for rows of different lengths beyond a length sufficient for 50 plants, say. These matters require much more extensive investigation before definite relationships can be established.

SUMMARY

A mathematical model of wheat bunt field trials has been constructed which seems to be adequate. The mean and spread of the heterozygous plants cannot be observed, but these can be calculated because the means and variances of the percentages for the homozygous and segregating rows can be observed and it can be assumed that the probabilities of infection for different types of plants are perfectly correlated as between rows.

The variance of the percentages for the segregating rows results from the probabilities of infection for the various genotypes present. For the data presented the variance for the segregating rows was very close to the binomial variance, although the variances for the homozygous rows are considerably greater.

This apparent inconsistency did not result from different *a* values for the genotypes of plants present. It was shown that by using a value of 1.6 for a_1 and a_2 the calculated errors resulting did not differ significantly from those observed.

It was assumed that the spreading effects noted in this experiment were due to environmental influences. Modifying factors would have a similar effect and probably the two could not be distinguished unless the modifiers affected only some genotypes.

This model should be of aid in interpreting complex hybrids in that the nature of the variances will be understood better. This is particularly true where a row or family is heterozygous or made up of plants of different genotypes which have different probabilities of infection. It also indicates that the spread of the percentages depends on the length of rows, the spread of infectivity levels, and the general level of infection.

The considerations involved in developing this model apply to developing models for any similar experiments.

The results of the mathematical model have been applied in detail to extensive genetic data from a cross between Banner Berkeley and Baart wheats. The results are consistent with the assumption that the spreading effect as measured by a is independent of genotype and length of row. This assumption is probably only true for certain ranges of genotypes and lengths of row.

LITERATURE CITED

1. BRIGGS, FRED N. Inheritance of resistance to bunt, *Tilletia tritici* (Bjerk.) Winter, in wheat. Jour. Agr. Res., 32:973–990. 1926.
2. ———. Inheritance of resistance to bunt, *Tilletia tritici*, in hybrids of White Federation and Banner Berkeley wheats. Jour. Agr. Res., 42:307–313. 1931.
3. ———. A third genetic factor for resistance to bunt, *Tilletia tritici*, in wheat hybrids. Jour. Gen., 27:435–441. 1933.
4. SALMON, S. C. Generalized standard errors for evaluating bunt experiments with wheat. Jour. Amer. Soc. Agron., 30:647–663. 1938.
5. STANFORD, ERNEST H. A new factor for resistance to bunt, *Tilletia tritici*, linked with the Martin and Turkey factors. Jour. Agr. Res., 33:559–568. 1941.

RECURRENT SELECTION FOR SPECIFIC COMBINING ABILITY IN CORN[1]

Fred H. Hull[2]

IMPROVEMENT of corn by isolation of inbred lines to be used in first generation crosses was suggested by Shull in 1909. The method has come to be widely used with so great success that its application to other species of plants and even of animals is being given serious consideration.

Identification of satisfactory inbred lines of corn for production of commercial hybrids has not been easily nor quickly accomplished. Difficulties with other species would seem to be greater than with corn. Furthermore, such data as are now available suggest to the writer that continued application of the method to corn may be less profitable than the first cycle of breeding has been for the improvement of yield.

From the foregoing viewpoint a modified breeding plan for the development of higher yielding corn has been outlined. Since experimental evaluation must require several years and possibly application by more than one operator, the plan is presented here on theoretical considerations alone. Current practice in developing superior hybrid corn rests squarely upon empirical results. Any theory of hybrid vigor is to be judged by the same data. However, if a theory may be developed to fit present data and in sufficient detail to predict results of untried experiments, it may have positive value in directing future work. If predictions from theory are then confirmed by experiment the theory may become more firmly established and more useful.

Hybrid vigor is here assumed to reside in the interactions of genes. It must then result from non-linear interaction of genes at different loci or between alleles. Either type of interaction alone or both together may explain hybrid vigor. Wright (13)[3] has supplied a test which, as applied to collected data on yield of corn by Neal (7), does not allow much non-additive interaction between genes at different loci. Richey and Sprague (9) found backcross yields almost exactly intermediate between parent and F_1 yields. In later data of Lindstrom (6) the mean deviation of F_2 means from mid-point of F_1 and parents is 2.3% of F_1 yield. The deviation of backcrosses is 3.6%. These values are hardly significant. Moreover, if any appreciable degree of hybrid vigor were due to complementary interaction, it might appear in an excess of F_2 yield over backcross yield. In Lindstrom's data the mean F_2 yield is 65.8 and backcross yield is 71.7. Neither complementary

[1]Contribution from the Department of Agronomy, Florida Agricultural Experiment Station, Gainesville, Fla. Published with the approval of the Director. Originally prepared for presentation at the 1944 annual meeting of the Society which was cancelled. (See this Journal, Vol. 36:989. 1944.) Received for publication September 8, 1944.

[2]Agronomist. The writer is grateful to Dr. Sewall Wright for kindly criticism of the main thought expressed in this paper and encouragement with respect to the proposed breeding plan for hybrid corn. Mr. F. D. Richey, Dr. E. W. Lindstrom, and Dr. M. T. Jenkins offered helpful suggestions and encouragement.

[3]Figures in parenthesis refer to "Literature Cited", p. 145.

nor geometric interaction is indicated as an appreciable factor in hybrid vigor of corn. However, it is conceivable that interactions tending to depress F_2 or the average of backcrosses below the midpoint of F_1 and parents may be balanced by other kinds of interactions tending in the other direction. High frequency of both kinds of interactions might provide constancy of the balance among many crosses of inbred lines. That the end result should then by chance coincide closely with the midpoint of F_1 and parents in each case may seem no more improbable than that there should be high frequency of non-linear interaction of alleles as discussed in the next few paragraphs and scarcely any non-linear interaction of non-allelic genes.

It is convenient to express non-linear interaction of alleles quantitatively for the present by graduating the interval of phenotype from aa to AA in units from 0.0 to 1.0. A heterozygote with value of 0.50 is strictly intermediate. Loci with heterozygote values near 0.50 can have little to do with hybrid vigor. It is best if both parents of a hybrid are fixed AA at those loci. As the heterozygote value of a locus increases towards 1.0, importance of the locus in hybrid vigor also increases and the value of having it fixed AA in the second parent decreases. If the heterozygote value is greater than 1.0, the locus is quite important as a source of hybrid vigor. It must be fixed AA in one parent and aa in the other to obtain maximum effect.

That heterozygote values greater than 1.0 for yield of corn occur at numerous loci is suggested first by the commonly observed excess of yield of F_1 hybrids over the sum of yields of two homozygous parents. Yields of inbred lines are usually less than one-half of the yields of their F_1 hybrids (6). If effects of different loci combine additively, the aA effects of loci heterozygous in F_1 of a cross of homozygous lines are summed in F_1. AA effects of the same loci are summed in the sum of the two parents. A residual composed of the aa effects of the same loci and all effects of loci not heterozygous is included once in the F_1 and twice in the sum of parents. Then, if aA effects are equal to corresponding AA effects throughout, the sum of parents will exceed F_1 by an amount equal to the residual. Since, as already noted, F_1 yields are commonly more, not less, than the sum of parents heterozygote values greater than 1.0 at numerous loci for yield of corn are strongly indicated in the writer's opinion. Further support of this view is provided by the failure of mass and ear-row selection to improve corn yields and by the failure of synthetic combinations of selected inbred lines to yield more than original stock. Selection which generally favors the heterozygote as selection for roan coat color in Shorthorn cattle leads to no fixation of genes as shown by Wright (1[illegible]). ?

A possible alternative conclusion to that of the preceding paragraph is that the genetic residual or least phenotype available by segregation from the cross is less than zero. Other alternatives which may appear superficially to be possible are close linkage and the very similar case of alleles of divergent function of East (1). Singleton (10) and Jones (5) have reported cases in corn where heterozygotes appeared to be more vigorous than either homozygote. Jones (5) has reviewed similar examples from other species. The essential point

seems to be that none of these cases provide examples of what might prove to be a sufficient explanation of the extreme heterosis observed in corn yields. Alleles WR and RW for white cob-red pericarp and red cob-white pericarp may provide a helpful example. The heterozygote WR/RW has red cob and red pericarp. If dominance of WR for pericarp color and of RW for cob color is complete the heterozygote may be equal to the sum of the two homozygotes. It will not exceed the sum of homozygotes without non-additive interaction between the alleles WR and RW over and above the dominance of each one to the other for its own separate function. The example as set up here seems to simulate very well the model of divergent alleles postulated by East. If there had been no dominance of each of East's alleles to the other for its own function the heterozygote would have been equal to but not in excess of the mean of the homozygotes. By inadvertently allowing this primary dominance East did achieve excess in the heterozygote with additive interaction between alleles over and above the primary dominance. There seems to be no mechanical dissimilarity between East's model, the example of cob and pericarp color, and the well-known theoretical model of complete repulsion linkage of two pairs which differ in primary function but not in end result. All of these examples provide heterozygotes exceeding either homozygote, but not exceeding the sum of homozygotes if their separate effects are cumulative.

There remain three possibilities of explaining present records on maize yields by gene action, *viz.*, (a) alleles A′ and A are each dominant to the other for their own primary effects and their primary effects are multiplied together or complement each other; (b) a positive interaction occurs between alleles a and A to the extent that aA exceeds AA, aa is neutral; (c) a negative interaction occurs between identities A and A to the extent that aA exceeds AA. All of these interactions provide heterozygotes exceeding the sum of the two homozygotes.

Until more definite evidence becomes available it seems best to design corn breeding plans on the assumption that one or more of the three above-listed interactions occurs at numerous loci for yield in maize to the extent that the sum of heterozygote effects exceeds the sum of homozygote effects by 20% or more. The breeding plan presented below has been designed specifically for that case. Fortunately it is also fully effective for the case where aA and AA effects are equal.

The breeding plan consists essentially of recurrent selection in a crossbred lot of corn for combining ability (high yield) with a single homozygous line which may be called the tester. The first generation cross of the tester line with the selected crossbred lot is to be the utility hybrid if selection is successful in building up a high complementary relation. Since selection based on appearance may be harmful where aA effects exceed AA effects and there is no guarantee from general experience that such selection is beneficial, it is not recommended.

BREEDING PLAN

First year.—Self-pollinate 100 or more plants in the crossbred lot and use pollen of each one separately on silks of the tester line. The 100 plants are to be taken at random with respect to evidence of inherent vigor. Plants which show evidence of pest or weather damage should be avoided.

Second year.—Record yield performance of the 100 test hybrids.

Third year.—Grow ear-rows from selfed seed of 10 or more plants which had the higher yielding test hybrids and make numerous crosses between but not within the rows. Selection of plants for intercrossing is to be only against pest and weather damage.

One cycle of breeding is completed in three years. The next cycle begins with bulked intercrossed seed from the last operation of the preceding cycle and the same tester line. Cycles may recur continuously. The product is the cross of the current crossbred lot or inbred lines from it and the tester line. The tester line should probably be chosen primarily for proved general combining ability. It should be a good pollinator if it is to serve that purpose in commercial seed production eventually. Prepotency of the tester line for undesirable characters is naturally to be avoided. The crossbred lot may be a common variety, a cross of varieties, or a cross of superior inbred lines. Breadth of ancestry would seem desirable.

Where no entirely satisfactory tester line is available, two related lines may be employed in parallel but separate operations, or in one operation using the cross of two lines as the tester. The single cross of tester lines will be the pollinator and the single cross of the crossbred lots the seed producer of the commercial double cross. Differences between the two tester lines may provide greater vigor in single crosses, but possibly at the expense of less vigor in the double cross.

The above outlined breeding plan would seem to be recommended by the following propositions:

1. With respect to any two loci which are heterozygous in original crossbred stock and possibly linked in some degree the genotypes are as follows:

$\frac{a\ b}{a\ b}$	$\frac{A\ b}{a\ b}$	$\frac{a\ B}{a\ b}$	$\frac{A\ B^*}{a\ b}$
$\frac{a\ b}{A\ b}$	$\frac{A\ b}{A\ b}$	$\frac{a\ B^*}{A\ b}$	$\frac{A\ B^*}{A\ b}$
$\frac{a\ b}{a\ B}$	$\frac{A\ b^*}{a\ B}$	$\frac{a\ B}{a\ B}$	$\frac{A\ B^*}{a\ B}$
$\frac{a\ b^*}{A\ B}$	$\frac{A\ b^*}{A\ B}$	$\frac{a\ B^*}{A\ B}$	$\frac{A\ B^*}{A\ B}$

The essential problem of current practice in corn breeding seems to be to distinguish between these genotypes as they occur in single crosses of homozygous lines. To the extent that the aA and

AA effects and the bB and BB effects are equal the nine starred genotypes are indistinguishable. The essential problem of the present breeding plan is to distinguish between the same genotypes as they occur in single plants of the crossbred stock. Where the tester line is fixed aabb, the greater frequency of favorable alleles in AB/AB plants will produce evident results in testcrosses. Selection between testcrosses of the present breeding plan as compared to selection between single crosses in current practice will thus have an advantage similar to that of calculating crossover values in a backcross, as compared to an F_2.

2. At any locus where the aA and AA effects are essentially equal and the tester line is AA, maximum hybrid vigor from that locus will be on hand at the beginning of breeding operations. The problem then is to accumulate high frequencies of favorable alleles in the crossbred lot at only those loci where the less favorable ones are fixed in the tester. The problem in current practice seems to be the accumulation of high frequencies of favorable alleles at all loci with respect to the entire active group of breeding lines. Since selection difficulty increases exponentially with number of independent loci and at a greater rate with linkage, probability of success in building a high complementary relation to a specific line may be many times greater than it is for obtaining a high complementary relation of two lines by random trial.

3. If effects of heterozygotes aA or A'A are superior to those of homozygotes aa, A'A' or AA, alleles a and A' may be as frequently favorable as is A. Selection in the present plan through successive cycles will always be directed towards whichever allele will provide the most favorable effect with the one that is fixed in the tester line and thus fully effective for increasing the frequency of that allele. Selection as in current practice through more than one cycle must be confused, sometimes for A and sometimes for a, thus being of small or no effect.

To the extent that excess vigor is found in heterozygotes of single loci the mean yield of two perfectly complementary homozygous lines will approach mean yield of homozygous lines derived at random from original stock. This on the assumption that two alleles at each locus occur with equal frequency in original stock. The average line found in the Florida program would be difficult or impossible to maintain with continuous selfing although it might produce some grain in the more favorable seasons. The possibility that a higher complementary relation may be maintained between a line and a crossbred lot than between two selfed lines is not supported in present theory, but it may yet be worth some consideration.

4. Recurrent mild selection where genetic variation exists soon builds up a total selection intensity far in excess of any feasible attainment by a single selection without recombination. Theoretically, where gene effects are additive and non-genetic variations do not occur, selection of the top 38% in one generation will shift the mean one standard deviation—selection of 7% will shift the mean two standard deviations. Selection in the present breeding plan operates on variation arising from different effects of the aa and aA geno-

types. Non-additive interaction between alleles does not interfere—see propositions 1 and 3. Selection operates on variation between means of testcrosses in replicated trials which should be largely genetic variation. It may be conservatively estimated, then, that the improvement effected in each cycle of breeding by saving the better 10% may amount to one standard deviation or more. On this basis the results obtained in four and six cycles would be equal to that of testing 12,000 and 385,000,000 inbred lines from the crossbred lot with the same tester line and identifying the best combination in each case. The values increase very rapidly after four or five cycles if genetic variation is maintained.

The foregoing statements are supported somewhat by unpublished results of recurrent selection for late plant type or high leaf number done by the writer. A small group of 10 or more plants in each generation was intercrossed to provide seed for the next generation. Selection was directed towards other characters besides leaf number. The total number of plants in four generations was 4,761. The same intensity of selection for leaf number alone might have been effected with only 200 plants but of course selection for some of the other characters may have improved leaf number. In terms of the F_2 standard deviation the mean leaf number of the sample selected in F_5 exceeded F_2 by 5.29 sigma. A similar sample might have been obtained by selecting the best 10 plants from 100,000,000 or more in a single generation, or the best 10 from 50 plants each generation through four generations.

Selection for high leaf number was quite effective through recurring cycles, presumably because of little or no non-additive interaction between alleles in the direction of selection, and relatively small non-genetic variance. Actually, means of the progeny of selected samples were nearly as high as the means of the respective selected samples. Nor were non-additive interaction or non-genetic variance in any considerable degree indicated by the usual tests. In the presently proposed breeding plan for high yield confusion of selection by interaction between alleles is avoided (propositions 1 and 3). Confusion of selection by non-genetic variation may be markedly reduced by replication of testcross trials to the extent that recurrent selection for combining ability may become as effective as was selection for leaf number in the above example.

5. The decline of genetic variation in the crossbred lot as frequencies of favored alleles are increased by selection will be slow if many loci are involved (11). Furthermore, it will be compensated in some degree by increase in frequency of coupling combinations. It is clear that if two gene pairs of equal effect each make contributions to the variance of a backcross equal to unity when independent, the contribution of each pair when the two are completely linked in coupling phase is two, or if in repulsion phase zero.

6. Combining ability of any strain or any single plant with a specific homozygous line is a measure of the mean complement of alleles in its gametes which are favorable in the specific combination, regardless of degree of homozygosity of the plant or strain. Jenkins (3) has ably supported a view which seems quite similar to the one pre-

sented here. In his final paragraph Jenkins states, "The topcrosses might be made after one generation of inbreeding, however, or might even be made at the time the open-pollinated plants are inbred the first time". Presumably the suggestion is that high combining ability be identified in open-pollinated or short time inbred plants and then fixed by continued inbreeding. In the present breeding plan, open-pollinated or crossbred plants which show high combining ability are immediately intercrossed (with no intervening inbreeding period) to begin another cycle of selection. On present theory a cross of two open-pollinated or crossbred plants is hardly inferior to random single crosses of homozygous lines from the same two plants as foundation material for a new cycle of breeding. Improvement which might be effected by selection within and between lines during an intervening inbreeding program would, on present theory, be very small in comparison with that effected by further cycles of the present breeding plan.

Propositions which do not seem to recommend the present breeding plan are as follows:

7. For those loci where the aA effect is less than the AA effect and the tester is fixed aa, maximum yield (AA in the hybrid) cannot be obtained by selection in the crossbred lot. The difficulty is greater for loci with lesser relative values of the aA phenotype. However, loci where heterozygote values are near or below 0.50 are more likely to be occupied by A alleles in original stock. Earlier selection for A alleles at those loci would not be greatly inhibited by non-additive interaction of alleles. Furthermore, the choice of a tester line with high general combining ability would include favorable alleles at such loci more frequently than unfavorable alleles.

8. For those loci where A'A effects may exceed aa, aA' and aA effects and the tester is fixed aa the maximum A'A effect cannot be obtained in the hybrid by selection in the crossbred lot. Frequency with which this difficulty would be encountered might also be lessened appreciably by earlier selection for favored alleles which has occurred in original stock and by choice of a tester line with proved general combining ability.

9. Genetic variance between testcrosses will be small and that within testcrosses large as compared to the variation between and within single crosses of a group of homozygous lines. Accuracy of measuring combining ability will therefore be low. Similar criticism has been voiced with respect to Jenkins' proposal that combining ability be tested early in the inbreeding program.

It is convenient to assume equal frequencies of a and A type genes in original stock and equal frequencies of loci fixed aa and AA in the tester line. The phenotype of aa may be assigned the coded value of zero and phenotypes of aA and AA the coded value of unity. Variance of the distribution 1aa + 2aA + 1AA is 3/16, which is the variance per locus between plants in original stock or between single crosses of a random group of homozygous lines. There is no variance within single crosses if the lines are homozygous. The mean yield of aa × (1aa + 2aA + 1AA) is ½ and of AA × (1aa + 2aA + 1AA) it is 1. The variance between 1 and ½ is 1/16 which is the

variance per locus between means of topcrosses of homozygous lines to original stock. Variance within topcrosses is 2/16. If single plants from the distribution (1aa + 2aA + 1AA) are crossed to aa, the testcross means are 0, ½, ½, and 1. Variance of this distribution is 2/16. If the locus is AA in the tester, there is no variance of testcross means. Hence the mean variance per locus between testcrosses is 1/16. Variance within testcrosses is also 1/16 per locus on the same basis.

Under the above assumptions a greater precision with testcrosses than with topcrosses would be obtained because variance within testcrosses is only half of that within topcrosses. Precision with single crosses would be considerably better than with testcrosses there being no within variance and the variance between being three times that for testcrosses or topcrosses.

10. Although high yield of corn is an extreme character in itself it may be a resultant of intermediate development of more primary characters, e. g., length of growing season, diameter of stalk, internode length, etc. Other more cryptic physiological characters may be optimum for yield at intermediate points. Selection for intermediacy may be much less efficient than selection of an extreme in the obtained rate of gene fixation (12). This proposition may be the most serious criticism of the present breeding plan or it may be of slight importance. In either case application of the proposed selection plan should at least throw some light upon the complex inheritance of yield in corn.

It does not seem necessary to attempt a complete summary of the foregoing propositions. Current corn breeding practice presumably includes successive cycles of breeding, although cycles recur irregularly and overlap a great deal. Better lines of one cycle are interbred to provide foundation stock for a succeeding cycle. The present plan is a variation of current practice in which the inbreeding interphase is eliminated and frequency of recurring cycles raised to maximum. The additional feature of a constant tester line eliminates confusion of selection by non-additive interaction of alleles towards higher yield. The breeding plan appears to be well recommended by the above 10 propositions but it must of course be proven in practice.

Many of the desirable characters of domestic plants and animals are apparently multigenic with the heterozygote at a large proportion of loci approximately equal to the favored homozygote in effect. Where this situation occurs and commercial propagation may be by crossing as in corn or by asexual multiplication of a single zygote as in sugarcane, the essentials of the present method may be employed. With sugarcane, for example, a stable though heterozygous clone may serve as the tester, although homozygosity in the tester will make for greater efficiency. Plants which are crossed with the tester need not be also selfed as in corn since they will live to be intercrossed when testcross results are available. Maintenance of a minimum of 10 breeding individuals per generation in the crossbred lot to avoid intense inbreeding and loss of genetic variation would seem desirable in any case.

In bisexual species of plants or animals where the breeding period of an individual is sufficiently long to span testcrossing and intercrossing, equal numbers of males and females may be crossed with the tester strain. The selected group may then contain both sexes to make intercrossing possible. Selection intensity might of course be curtailed by low reproductive rate of some animal species.

The present breeding plan may seem to be too much restricted by the necessity of choosing at the beginning a homozygous tester line. This line is to be maintained intact through many selection cycles and serve at any time as one parent of the current commercial hybrid. After a few cycles some barrier to further progress which has been hidden may come to light in the tester. This fear cannot now be explained away. But it must not be allowed to assume undue proportions relative to the impasse presented by many linked genes. The frequency distribution of number of loci represented aA or AA in single crosses of inbred lines of corn is presumably narrow. Frequencies over a considerable part of the range at either end are exceedingly small. The present breeding plan is conceived as a way around the impasse by frequent recurrence of selection and avoidance of confusion arising in non-linear interaction of alleles.

The plan may perhaps be further criticized in that it does not allow for much improvement on the tester side. The first reply is that the objective is improvement of hybrid yield not inbred yield. If yields of inbred lines of corn in commerical production were either doubled or halved, cost of producing doublecross seed would hardly be affected more then 10 cents a bushel either way. To the extent that excess vigor arises from heterozygotes the best combination must involve average lines. Present highly selected lines may too frequently be fixed AA at the same loci and in that sense be already too good. But if this point is unimportant the prime problem is still hybrid yield which is to be obtained by high complementary relation between parents more than by intrinsic merit of parents.

Some corn breeders, including the writer, have one or a few favored lines which are receiving considerable attention. The favored line is crossed to a number of other lines. Crosses are followed with backcrosses. Extensive selection within and between backcrosses and intercrossing of the better appearing ones has been done. The main improvement thus effected is in visible characters and there is some danger of loss of combining ability. It would seem that a line which merits such attention might also merit the further attention necessary to build a strain of high complementary value to it. The two programs might operate simultaneously without too much loss of efficiency in selection for combining ability, especially if second or third backcrosses were employed in improving the tester line. (See Hayes and Immer (2) for a late review of backcross and convergent methods of improving inbred lines.)

One operation of the present breeding plan could probably serve three or more maturity zones if early, medium, and late variants of the tester line were preserved and uniformity for the character avoided in the crossbred lot. Early, medium, or late inbred lines could be extracted from the crossbred lot at any time. One operation

of the plan saving the best 10 from 300 per cycle would be many times more efficient than three separate operations saving the best 10 from 100 in each cycle. But how many maturity zones may be spanned profitably in employing this principle is a problem for experimentation.

If the maturity range thus spanned seems to be too narrow the possibility may be considered that a singlecross hybrid has appeared in the central corn belt with yield 20% above the next highest hybrid. The parents of this singlecross would be in wide demand for use on opposite sides of doubles of varying maturity ranges. The parent lines would be immediately requested by the writer for use in Florida. The late selection mentioned under proposition 4 has three more leaves and is 12 to 14 days later than common Florida field corn. It was developed specifically for a non-recurrent parent to convert any outstanding northern lines to southern maturity type—the selection for late type being already done in sufficient excess to allow full recovery of desired type in a first or even a second backcross to a northern line. No truly outstanding lines have yet appeared in the more extensive northern work. But foregoing theory indicates the possibility of building outstanding complementary pairs of lines by the present breeding plan.

The Florida corn breeding program has included test plots at Gainesville and Quincy in about equal numbers for a number of years. If one operation of the present breeding plan is now installed at each location present land and other facilities must be requisitioned for about 15% or less of the total in use. The remaining 85% may be continued with current corn breeding practice. Certainly this 15% is not too great a price to pay for the privilege of hedging on the possibility that aA effects do frequently exceed AA effects for yield of corn and that current practice in later cycles may prove ineffective with yield. But it must be clear also that the theory indicates greater efficiency for the present plan if aA effects are near to but not in excess of AA effects.

If the new plan is adopted entirely, present facilities of the Florida program will accomodate 18 separate operations with 100 testcrosses in six replications for each. Each operation might employ a homozygous tester line to thus provide 18-high-yielding single combinations. If the 18 testers are unrelated and aA effects do exceed AA effects, considerable yield reduction is to be expected in combining the singles into doubles. If aA effects do not exceed AA effects, there will still be some specific combining ability in each single where the crossbred lot has been especially selected to cover the weaknesses of the tester line but not of any other unrelated line. Full efficiency seems to demand as close relation of two lines as is practicable for their cross to be the tester, and the pollinator in commercial seed production. An alternative with lower efficiency for yield improvement but higher efficiency for production of commercial seed is to use a proven and established seed singlecross as the tester and as the seed parent of commercial hybrid seed. If aA effects are frequently in excess, selection in the crossbred lot for a-type genes at loci fixed AA in the tester might render the crossbred

lot unfit for bearing commercial seed. Greater uniformity of commercial seed and wider range of pollen shedding are further advantages of this latter alternative.

The inflexibility that arises from high specific combining ability developed within each operation of the present breeding plan is to some extent relieved by broad breeding in crossbred lots. Special characters not concerned with yield should remain amenable to selection in crossbred lots. Greater efficiency will of course be obtained if such selection is concurrent with that for combining ability and if the tester may be chosen with the desired characters at the start.

Finally some alternative breeding plans may be considered. Jenkins (3) has proposed for the improvement of open-pollinated corn where hybrids are not feasible that one-generation selfs be topcrossed with the parent stock. The selfs having the better topcrosses are then recombined into a synthetic variety. After a few generations of isolated open-pollination for mixing the process is repeated. Incidentally, it may be said that no real value in extra generations for mixing recombined stock has been discovered in considering the breeding plan which is the main subject of this paper. Sufficient mixing occurs in proceeding from cycle to cycle. Presumably the objective in Jenkins plan is increased frequency of the more active favorable alleles. Increased frequency of favorable alleles requires that they more often occur homozygous. The objective might as in Richey's convergent improvement (8) be complete homozygosity of favorable genes. In that case it would seem well to dispense with the topcrosses in Jenkins' plan and base selection directly on homozygous superiority. First generation selfs would be measured for production and the better ones recombined; the next cycle of selfing and selection following immediately. This plan might be considerably more powerful than convergent improvement in progressing towards the goal of homozygous excellence because of greater genetic variation and more frequently recurring cycles of selection.

The breeding plan immediately above was begun by the writer in 1928 in the belief that selection within or between lines selfed more than two or three times was likely to be confused by abnormal gene interactions. Selection based on appearance should be done with limited inbreeding. The plan was abandoned, after completing one cycle, in the belief that early efforts would be best directed towards development of homozygous lines and selection of the more vigorous ones. In present belief the plan may fail because of excess vigor of heterozygotes at many loci which would confuse selection. Current corn breeding practice may fail in a second cycle and also convergent improvement for the same reason. All three of these breeding plans may be partly successful, however, to the extent that loci occur where the aA effect is not in excess of the AA effect.

The plan of recombining selected lines is followed in a general way with wheat and other self-fertilized crops except that lines are not chosen for recombination until after several generations of natural selfing. Perhaps more rapid progress might be made in such crops if selection cycles recurred more frequently with recombination of one- or two-generation selfs.

Where hybrid vigor may be utilized, selection in a crossbred lot for high complementary relation to a specific homozygous line would seem to be a more promising method of improving vigor and production if present theory of the genetic basis of hybrid vigor is essentially correct.

LITERATURE CITED

1. EAST, E. M. Heterosis. Genetics, 21:375–397. 1936.
2. HAYES, H. K., and IMMER, F. R. Methods of Plant Breeding. New York: McGraw-Hill. 1942.
3. JENKINS, MERLE T. The effect of inbreeding and of selection within inbred lines of maize upon the hybrids made after successive generations of selfing. Iowa State Col. Jour. Sci., 9:429–450. 1935.
4. ————. The segregation of genes affecting yield of grain in maize. Jour. Amer. Soc. Agron., 32:55–63. 1940.
5. JONES, D. F. Equilibrium in genic materials. Proc. Nat. Acad. Sci., 30:82–87. 1944.
6. LINDSTROM, E. W. Analysis of modern maize breeding principles and methods. Proc. 7th. Int. Gen. Cong. 1939.
7. NEAL, N. P. The decrease in yielding capacity in advanced generations of hybrid corn. Jour. Amer. Soc. Agron., 27:666–670. 1935.
8. RICHEY, F. D. The convergent improvement of selfed lines of corn. Amer. Nat., 61:430–449. 1927.
9. ———— and SPRAGUE, GEORGE F. Experiments on hybrid vigor and convergent improvement in corn. U. S. D. A. Tech. Bul. 267. 1931.
10. SINGLETON, W. R. Hybrid vigor in the intra-inbred cross P39 × C30 in maize. Records Gen. Soc. Amer. No. 12. 1943.
11. STUDENT. Evolution by selection. Eugenics Rev., 24:293–296. 1932.
12. WRIGHT, SEWALL. Systems of mating. IV. The effects of selection. Gen., 6:162–166. 1921.
13. ————. The effects of inbreeding and crossbreeding on guinea pigs. U. S. D. A. Bul. 1121. 1922.

CHEMICAL AND STRENGTH DIFFERENCES IN DEW-RETTED HEMP FIBER[1]

LYLE E. HESSLER[2]

PRODUCTION of good quality hemp fiber depends largely on the retting process. While dew retting is a comparatively simple operation for freeing the fiber, control of the large number of factors which enter into retting is very difficult. Well-retted fiber should have good strength and a uniform slate-gray color. Under-retted fiber is green or light-colored and does not have the keeping and spinning qualities of well-retted hemp fiber. Over retting usually gives the proper color but may produce weak fiber. Some measure of control may be had by shocking hemp before spreading. This procedure seems to condition the hemp against over retting by slowing down microbiological action. Turning the hemp in the field gives more uniform retting, while picking up the straw to stop retting at the proper time is important.

In order to understand more about the retting process, studies were conducted at the Kentucky Agricultural Experiment Station on the chemical composition of the green, unretted fiber, and of fiber produced at various stages of retting, including fall and winter retting, from both Kentucky and Chilean varieties. The actual strength of these fibers was determined by breaking-strength tests in order to find out the effect of retting on strength and to correlate strength, if possible, with chemical composition.

METHODS

For analysis the hemp fiber was sampled at random and ground to 60-mesh in the intermediate Wiley mill.

Cellulose was extracted by the method of Norman and Jenkins (1).[3] Medium-porosity fritted glass crucibles were used to facilitate manipulation in removing extraneous material from cellulose. Two treatments with neutral sodium hypochlorite solution and three with acid hypochlorite solution were found sufficient to give reasonably pure cellulose. After washing the sample several times with 5% sulfuric acid solution and four or five times with boiling water, the crucible was put into a 250-ml wide-mouth Erlenmeyer flask, where oxidation with a sulfuric acid dichromate solution was carried out and the analysis made according to the method of Kettering (2). Because of the associated xylan present in hemp cellulose, a slightly higher factor was necessary. One milliliter of normal potassium dichromate was equivalent to 0.0068 gram of cellulose.

---

[1]Cooperative investigation of the Division of Cotton and Other Fiber Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture, in cooperation with the Kentucky and Michigan Agricultural Experiment Stations and published by permission of the Director of the Kentucky Agricultural Experiment Station. Presented in part at the annual meeting of the American Society of Agronomy, held in Cincinnati, Ohio, November, 1943. Received for publication September 16, 1944.

[2]Associate Chemist, Division of Cotton and Other Fiber Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture. The author acknowledges assistance given by Prof. E. J. Kinney, Kentucky Agricultural Experiment Station, Dr. S. T. Dexter, Michigan Agricultural Experiment Station, and Dr. B. B. Robinson, U. S. Department of Agriculture.

[3]Figures in parenthesis refer to "Literature Cited", p. 154.

Lignin was determined by 72% sulfuric acid in the cold with a pretreatment of mild acid hydrolysis to remove interfering substances, as suggested by Norman and Jenkins (3).

The dicarboxylation method, as used by Dickson, Otterson, and Link (4), was employed to determine pectic substances by measuring carbon dioxide produced by boiling the sample with 12% hydrochloric acid. Carbon dioxide multiplied by the factor 5.67 gave a value for pectic substances. The dicarboxylation method as used here is open to some criticism, since it has been shown that the method is not as specific for uronic acid as formerly believed; however, the method gives reproducible results and, for comparison, it is believed the method has merit.

Pentosans were determined as furfural. The method used was that of Reeves and Munro (5) which was originally designed for the determination of pentoses; however, after experimentation, it was concluded that interference from anything other than pentosans was at a minimum.

Nitrogen and ash were determined by recognized and acceptable methods.

All determinations were on a moisture-free basis.

Breaking strength of the hemp fiber was measured on a Scott tester, Model D H. A portion of the fiber 1 foot in length was cut from the center of each hank to be tested. The samples were combed with a wire brush to remove loose ends. The orderly fibers were then cut to 25-cm lengths and conditioned at 65 ± 1% relative humidity by placing them in a desiccator over supersaturated sodium nitrite solution. Spool-type clamps were used, and their distance from center to center was 3 inches. Ten breaking tests were made on each sample, and the average breaking strength was reported in kilograms per gram of fiber.

EXPERIMENTS AND RESULTS

UNRETTED VS. RETTED HEMP FIBER

Unretted hemp fiber is quite uniform in chemical composition. Slight variations from the average will be affected by date of harvest and character of growth. Growing conditions may result in the fiber being fine, coarse, or flaggy. The commercial hemp fiber grown and retted in this country is composed of about 80% cellulose and lignin which may be classed as the more insoluble fraction. The other 20%, or partially soluble fraction, is composed of nitrogenous compounds, pectic substances, pentosans, extractable substances, and ash. Studies were made on these latter materials to determine to what extent their concentration may serve as an index of degree of retting, since they are depleted more or less in the retting process. A number of different forces seem to play an active part in this action, namely, sunlight, moisture from rain and dew, microorganisms, and possibly the expansion and contraction brought about by temperature changes. While these factors act to free the fiber, they also play a part in weakening it. This is because, under favorable moisture and temperature conditions, the microflora uses up the soluble constituents and, as the more usable food source is depleted, cellulose is attacked.

Obviously, to obtain strong fiber, retting should be allowed to proceed only until the soluble constituents are used up or nearly so. It is rather difficult, however, to determine when this stage has been reached. Color is not a reliable guide because the gray color desired by the trade may not be acquired until the fiber is overretted and thus weakened. Underretting gives strong fiber, but its keeping qualities may suffer, especially in humid climates.

Some indication of how hemp fiber is affected by dew retting may be found in Table 1. The first three fibers are from the same hemp

crop, and all were broken out and scutched in a commercial hemp-breaking mill. Apparently, machine breaking did not injure the green fiber, as indicated by breaking-strength tests.

TABLE 1.—*Chemical composition and strength of retted vs. unretted hemp fiber.**

Fiber	Ret	Cellulose, %	Lignin, %	Pentosans, %	Pectic substances, %	Nitrogen, %	Ash, %	Breaking strength, kgs. per gram
Green...	Unretted	64.7	6.66	5.78	9.60	0.46	4.34	192.0
Line	Retted	72.4	7.80	4.79	7.82	0.77	3.57	117.4
Tow.....	Retted	69.2	8.05	4.87	8.06	0.81	3.48	61.6
Top fiber	Retted	67.4	9.05	4.41	8.38	0.73	4.55	—
Bottom..	Retted	70.0	8.44	4.71	9.58	0.54	3.90	—

*The chemical analyses are on a dry-weight basis.

The unretted hemp fiber is low in cellulose and lignin and high in pectic substances and pentosans. The combined insoluble fractions, cellulose and lignin, in unretted fiber analyzed approximately 70%, as compared with 80% for retted hemp fiber. This gain of 10% in the retted hemp fiber results from the loss of more soluble constituents during retting. Pectic substances and pentosans, as was expected, were much lower in well-retted than in unretted fiber. The tow contains most of the weaker, over-retted top part of the hemp fiber derived from the greener, less mature part of the plant, which is more likely to over ret. The breaking strength of the tow fiber was very low, a condition resulting from over retting. The line fiber was considered of good quality, although it was much weaker than the unretted fiber. The chemical analyses of the fiber from the top and bottom part of the hemp plant (Table 1) further confirm the statement that over retting takes place at the greener, top part of the hemp plant by showing less pectic substances and pentosans, a higher lignin, and a lower cellulose content for the top fiber.

INFLUENCE OF SUNLIGHT ON RETTING

A study was made to determine the effect of sunlight on retting. Experienced hemp producers in Kentucky believe dew retting immediately after harvest to be detrimental because of "sun scald". For this reason, the hemp is shocked when harvested in late August and early September and spread to dew-ret in November during cooler weather. The term "sun scald" is vaguely defined but apparently refers to a condition in which the hemp bleaches unevenly and fails to ret uniformly. In order to study this problem, 500 pounds of harvested hemp were shaded during the day but fully exposed to dew and rain. An equal amount of similar hemp was allowed to ret in the open and served as a check on the shaded hemp. A bundle of fresh green hemp from the same lot was spread and dried rapidly at 75° C. This hemp also was shaded during retting. All the hemp straw was turned after retting 3 weeks. Both the shaded and the unshaded checks were exposed to equal amounts of rain; however, the

check required 33 days to ret while the shaded hemp required 45 days. The heated and shaded hemp seemed to ret at about the same rate as the shaded, although the former gave a more uniform and a darker color. This may have been due to early destruction of enzyme action with subsequent effect on the microflora of retting.

The hemp straw was prepared by breaking and scutching in a commercial mill. The fiber yield and fiber analysis are shown in Table 2.

TABLE 2.—*The change in quality and chemical composition of hemp fiber brought about by preheating and shading during retting.**

Fiber	Ret	Cellulose, %	Lignin, %	Pentosans, %	Pectic substances, %	Nitrogen, %	Ash, %	Line fiber, %	Breaking strength, kgs per gram
Check.....	Open	72.5	8.40	4.37	7.26	0.57	2.99	61	120.4
Shaded....	Covered	73.1	8.47	3.89	7.82	0.51	3.44	67	104.8
Heated and shaded ..	Covered	75.2	7.84	3.98	7.82	0.49	3.03	—	133.9

*The chemical analyses are on a dry-weight basis.

The chemical composition of the unshaded check and shaded hemp fibers is very nearly identical. A little more pectic substances and ash were removed by retting in the open. The strength of the unshaded hemp was greater than that shaded by 120.4 kgs per gram as compared with 104.8 kgs per gram. Heating prior to retting produced the greatest change in the fiber and also gave fiber of the greatest strength. These differences produced by heating may perhaps be due to the fact that the heating slowed down the action of microorganisms of retting in such a way as to retard fiber decomposition. This preconditioning of the fiber by heating or drying, such as takes place in shocking or stacking the green hemp, seems to give some measure of control against over retting. A record of 12 hemp growers in Kentucky in 1942, 5 of whom shocked their hemp before retting while the other 7 spread their hemp to ret at cutting time, is of interest. Shocking before retting gave 52.7% line fiber, while retting at cutting time gave 32.9% line fiber. This was an exceptionally wet fall and winter which did not allow the hemp to be shocked when retting was complete. Shading apparently did not stop fiber decomposition over the longer retting period and gave lower breaking strength; however, it did produce more line fiber, 67% as compared with 61% for the check. The values for strength and percentage of line fiber seem to be contradictory and will need further experimental work to substantiate or correct the results.

EFFECT OF VARIETY, RATE OF PLANTING, AND TIME OF RETTING ON CHEMICAL COMPOSITION AND STRENGTH OF FIBER

A variety, rate-of-planting, and time-of-retting field experiment was undertaken at the Michigan Agricultural Experiment Station

in 1942. The hemp straw from each experimental plot, after cutting, was divided and one part allowed to ret in the fall and another part was retted in the winter. Fall retting was allowed to continue for 29 days and winter retting for 49 days. The fiber was later prepared by machine breaking, sampled, tested for strength, and analyzed for cellulose, lignin, pectic substances, pentosans, nitrogen, and ash. The fall-retted fiber was noticeably green and under retted, while the winter-retted samples, according to accepted color standards, were perhaps slightly on the under retted side. The data for chemical composition are given in Table 3.

TABLE 3.—*Dry weight composition of retted hemp fiber with analysis of variance of the constituents.*

Seeding rate, pecks per acre	Retting period	Cellulose, %	Lignin, %	Pectic substances, %	Pentosans, %	Protein, Nx6.25, %	Ash, %	Analysis total, %
				Kentucky				
3	Fall	70.1*	7.24	7.27	4.38	5.09	3.23	97.31
3	Winter	73.2	7.32	5.32	3.65	4.96	2.37	96.82
4	Fall	68.9	7.64	7.70	4.24	5.67	3.27	97.24
4	Winter	73.2	7.03	5.45	3.44	4.73	2.37	96.37
5	Fall	67.7	7.79	8.32	4.73	5.68	3.21	97.65
5	Winter	72.3	7.57	5.92	3.66	5.24	2.51	97.11
				Chilean				
3	Fall	71.9	6.02	8.54	4.70	3.75	2.63	97.15
3	Winter	74.6	6.32	6.66	3.70	3.59	2.07	96.88
4	Fall	73.1	5.96	7.90	4.40	3.87	2.71	97.39
4	Winter	73.8	6.49	6.34	3.74	3.96	2.10	96.29
5	Fall	73.6	5.80	8.17	4.70	3.62	2.62	98.68
5	Winter	73.9	6.71	6.43	3.86	3.80	2.07	96.94
				Comparisons				
Kentucky.....		70.9	7.44	6.67	4.02	5.25	2.83	
Chilean.......		73.5	6.22	7.28	4.19	3.77	2.37	
Dif. and significance....		-2.6**	1.22**	-0.61**	-0.17	1.48**	0.46**	
3 pecks per acre		72.4	6.72	6.95	4.11	4.35	2.57	
4 pecks per acre		72.2	6.78	6.85	3.95	4.56	2.61	
5 pecks per acre		71.9	6.97	7.21	4.24	4.58	2.60	
3–5 dif. and significance		0.5	-0.25	-0.26	-0.13	-0.23	-0.03	
Fall retting...		70.9	6.74	7.98	4.52	4.61	2.94	
Winter retting		73.5	6.91	6.02	3.67	4.38	2.25	
Dif. and significance....		-2.6**	-0.17	1.96**	0.85**	0.23	0.69**	

*Each value is the average of six replications.

**Significant odds better than 99 to 1. Only interactions that are significant are retting season X variety for cellulose and Lignin.

The chemical data indicate a higher level of cellulose, pentosans, and pectic substances in fiber of the Chilean variety, with a higher concentration of lignin, protein, and ash in the fiber from the Kentucky seed. The fall-retted samples show the effect of under retting by giving higher values in the more soluble fractions, such as pectin, pentosans, protein, and ash. These higher values of soluble constituents in the fall-retted fiber lower the percentage of cellulose as compared with the percentage in a well-retted fiber. It has been shown that lignin increases and reaches its highest concentration late in the plant's life cycle and therefore is associated with maturity; consequently, the time of harvesting the hemp will play a part in the ultimate concentration of lignin in the fiber. Microorganisms do not readily attack lignin, and it is doubtful if those present in retting have this faculty to any great extent. Thus, by removing the soluble fractions during retting, the percentage of lignin remaining in the fiber should continue to increase with increased retting. The same reasoning can be applied to cellulose, although it has been demonstrated that the fungi associated with dew retting will destroy cellulose as their more readily available food source is depleted.

Lignin values for fall- and winter-retted hemp fiber of the Chilean variety agree with this line of reasoning, i. e., the highest level is found in the winter-retted fiber. The Kentucky variety gave the highest value in the fall-retted fiber, which is difficult to explain by the action of the retting process. The solution may be in greater concentration differences brought about by the different degrees and ease of retting between the two varieties of hemp fiber. This may be seen in the cellulose fraction from the Chilean fiber where the retting difference between fall and winter is only 1 to 2% while for Kentucky fiber it is 3 to 4%. From the fall- and winter-retting averages it is apparent that the concentration differences for the Kentucky fiber are greater for all fractions except lignin. Since greater concentration changes in the more soluble fraction indicate greater ease of retting, it is probable that microbiological action destroyed some cellulose in the fall retting when the plants were fresh and green without attacking the lignin. This may account for the higher percentage of lignin in the fall-retted fiber, which would indicate that at harvest the Kentucky hemp was greener and less mature while the Chilean hemp was more mature and not so readily attacked by microorganisms.

The chemical data indicate that the seeding rate has had an effect on retting by giving lower cellulose and lignin values and higher concentration of the more soluble fraction at the higher rates of seeding. This can be accounted for by assuming that the larger amounts of hemp produced by the heavier stands would ret more slowly after spreading. Table 3 shows that hemp fiber from the Kentucky variety has significantly less cellulose and pectic substances and more lignin, protein, and ash. The retting period influenced significantly the composition of the fiber, as shown by the fall period having lower cellulose and a higher value for pectic substances, pentosans, protein, and ash. Highly significant differences were found for the interactions for season of retting and variety for cellulose and lignin.

TABLE 4.—*Fiber quality as determined by breaking strength and grade as influenced by varieties, seeding rates per acre, and periods of retting.*

Kentucky						Chilean					
3 pecks		4 pecks		5 pecks		3 pecks		4 pecks		5 pecks	
Fall retted	Winter retted	Fall retted	Winter retted	Fall retted	Winter retted	Fall retted	Winter retted	Fall retted	Winter retted	Fall retted	Winter retted
Strength of Fiber, Kgs											
116.4	101.2	124.8	102.5	122.4	92.1	104.3	101.7	113.5	96.5	102.2	97.1
102.1	90.0	129.5	111.3	130.5	92.1	95.2	89.9	94.2	123.3	114.0	105.0
109.8	97.5	125.4	116.1	103.8	103.0	125.5	87.4	109.7	72.6	125.2	73.6
120.0	84.7	125.2	90.0	120.9	118.7	89.7	77.9	91.8	85.7	111.1	102.0
Grade of Fiber*											
White	White	White	White	White	White	White	Blue	White	White	Red	White
White	White	White	Blue	White	White	White	Red	Red	Red	White	White
White	White	White	Blue	White	Red	Red	Red	White	Red	Red	Red
White	White	Red	Red	White	Blue	White	White	White	White	White	White

	Breaking strength, kgs		Fiber classification	
	Mean	Difference	Mean†	Difference
Comparisons:				
Varieties				
Kentucky	109.6	—	4.00	—
Chilean	99.6	—	3.33	—
Advantage for Kentucky		10.0**	.	0.67
Seeding rate per acre				
3 pecks	99.6		3.75	
4 pecks	107.0		3.63	
5 pecks	107.1		3.63	
Advantage 5 pecks over 3 pecks		7.5		−0.12
Time of retting				
Fall	112.8		3.58	
Winter	96.3		3.75	
Advantage for fall retting		16.5**		−0.17

*Commercial fiber grades: Blue, white, and red in order of decreasing quality.
**Significant odds better than 99 to 1. No interactions significant.
†Assigned values: 6 for blue, 4 for white, and 2 for red.

In Table 4 are shown the effects of variety, seeding rate, and retting period on fiber quality. The breaking strengths are reported in kilograms per gram of fiber, while the fiber grades were commercially graded. The table shows that the fiber from the Kentucky hemp is of significantly greater strength than the fiber from the Chilean variety. There is a tendency for the stronger fibers to be associated with the heavier seeding rates. This may be due to less retting because of the heavier stand, finer and better quality fiber in the heavier seeding, or it may be a combination of the two factors. Strength tests prove that fall-retted or under retted fiber is stronger than that obtained from winter retting. This is apparent in the averages and especially those from the Kentucky fiber. The average of the three fiber grades is related to strength; that is, the white grade average strength is stronger than the red grade and the blue grade is stronger than the white grade. This relation is more pronounced in the Kentucky variety. The average of all blue grades was 108.5 kgs per gram; of all white grades, 104.4 kgs per gram; and of all red grades, 102.7 kgs per gram; however, it must be noted that there are only four blue grades from the four replications tested.

CONCLUSIONS

Retted hemp fiber is composed of about 80% cellulose and lignin, while the remaining 20% or partially soluble fraction is made up of nitrogen compounds, pectic substances, pentosans, ash, and other extractable substances. Unretted hemp fiber consists of about 30% of the partially soluble fraction. By retting, part of it is removed in order to free the fiber. When the fiber is exposed to microbiological action, it is weakened and, as a result, the breaking strength varies inversely with the length of the retting period.

Exposure to the sun shortens the time of retting.

Damage to hemp fiber during retting may occur to a greater extent when the fresh green plants are retted than if the plants are allowed to cure by shocking; further, the younger top part of the plant may readily result in weaker fiber.

Winter retting compared with fall retting usually has been observed in practice, and substantiated by the experiment reported here, to result in a better color but weaker fiber. This condition is probably due to the slower, longer retting period. The chemical composition of winter-retted fiber was lower in the more soluble fractions, which indicates more retting.

Fiber grown from Kentucky hemp seed had a different level of constituents and greater strength than fiber from Chilean hemp.

In general, the breaking-strength tests were related to commercial fiber grades; however, the lower grade had some of the strongest fibers, which can be attributed to under-retting.

LITERATURE CITED

1. NORMAN, A. G., and JENKINS, S. H. A new method for the determination of cellulose. Biochem. Jour. 27:818-831. 1933.
2. KETTERING, J. H. Quantitative determination of cellulose in raw cotton fiber. Ind. and Eng. Chem., Anal. Ed., 14:432-434. 1942.

3. NORMAN, A. G., and JENKINS, S. H. The determination of lignin. Biochem. Jour., 28:2147–2168. 1934.
4. DICKSON, A. D., OTTERSON, H., and LINK, K. P. A method for the determination of uronic acid. Jour. Amer. Chem. Soc., 52:775–779. 1930.
5. REEVES, R. E., and MUNRO, J. Quantitative determination of pentoses. Ind. and Eng. Chem., Anal. Ed., 12:551–553. 1940.

NOTES

COMPARATIVE SOIL TESTS

RAPID chemical soil tests have long been considered by agronomists to be potentially useful for obtaining some idea regarding the nutrient status of soil. The degree to which such tests have been helpful in field work has varied with kind of soil, with local conditions, and with the experience of the agriculturist using the test. By the late 'thirties, interest in these tests was sufficiently widespread to justify a collaborative study of soil testing methods and such a program was accordingly sponsored by the American Society of Agronomy (2)[1] and by other organizations.

Staff members of 14 State experiment stations furnished a group of 31 soils used for the test and these 14 stations, together with other institutions, took part in the collaborative work. M. F. Morgan of the Connecticut Agricultural Experiment Station acted as Chairman of the committee in charge of the testing program, known as the Soil Testing Committee, and M. S. Anderson of the former Bureau of Chemistry and Soils, U. S. Dept. of Agriculture, took charge of the soil samples and received from each collaborator a copy of the results sent to the Chairman. Use has been made of these soil samples by a considerable number of organizations, particularly in the eastern part of the United States. A brief description of the soils and their characteristics was published in a bulletin of this Department (1). The data received from collaborators were summarized by Morgan in a mimeographed report (3).

Each collaborator used the methods currently employed in his laboratory. This led to the use of widely varied extractants and to wide variations in other features of the tests. Some collaborators used weak solutions of strong acids; others used concentrated solutions of weak acids or their salts. Results obtained with these two widely different groups of extractants were considered separately in Morgan's report. This report rates the results of the various collaborators on a relative scale of zero to 10. In order to have a value of 10 the constituent of a soil must be voted highest by all collaborators.

The original collaborative study did not include Neubauer tests, but such determinations have been made with facilities recently provided by this Division. The work of the Soil Testing Committee was officially closed several years ago, but the soil samples are still in the hands of the original custodian. The main interest in Neubauer data probably will lie in its relation to the relative productivity estimates made by those who selected and collected the soils. There

[1]Figures in parenthesis refer to "Literature Cited", p. 158.

TABLE 1.—*Potash and phosphorus extracted from soils by Neubauer procedure, together with former data from other sources.*

Sample No.	Kind of soil and location	Native fertility	Attained productivity	Response to*		pH by glass electrode (1)	Available potash by different methods			Available phosphorus by different methods	
				K	P		Neubauer, mg per 100 grams	Exchangeable, mg per 100 grams†	Rating by Soil Testing Committee (3)	Neuabuer, mg per 100 grams	Rating by Soil Testing Committee (3)‡
C 4739	Cecil sandy clay loam, Ga.	Low	Med. high	Medium	High	5.0	6.3	14	3.0	2.6	1.7
C 4740	Cecil sandy clay loam, Ga.	Low	Med. high	Medium	None	4.9	6.2	13	2.9	10.5	6.7
C 4741	Dunbar fine sandy loam, N. C.	Fair	Good	Medium	Medium	4.6	−0.1	13	2.2	0.7	2.3
C 4742	Dunbar fine sandy loam, N. C.	Fair	Good	Medium	Medium	4.9	3.3	16	3.4	0.4	5.2
C 4743	Kempsville sandy loam, Va.	Fair	Fair	Medium	High	5.1	12.0	13	5.4	6.3	7.4
C 4744	Kempsville sandy loam, Va.	Fair	Low	Medium	High	5.4	13.2	12	4.0	2.0	2.7
C 4745	Brookston clay, Ohio	High	Very high	Doubtful	Doubtful	6.4	58.5	22	3.6	7.2	6.6
C 4746	Wooster silt loam, Ohio	Med. low	High	High	High	6.9	8.5	15	1.9	2.4	1.4
C 4747	Grundy silt loam, Missouri	Medium	—	Medium	Very low	4.9	—	13	2.5	—	1.7
C 4748	Oswego silt loam, Missouri	Low	—	Medium	Very low	4.9	10.4	11	2.9	2.9	1.7
C 4749	Merrimac sandy loam, Conn.	Medium	High	Doubtful	None	5.2	18.8	19	7.5	14.4	8.4
C 4750	Charlton fine sandy loam, Conn.	Low	Med. high	Doubtful	High	4.7	12.5	12	3.0	1.0	1.7

C 4751	Honeoye silt loam NP treatment, N. Y.	High	High	Doubtful	Doubtful	7.1	20.6	16	2.3	5.6	5.5
C 4751A	Honeoye silt loam NPK treatment, N. Y.	—	—	—	—	7.3	25.1	14	2.7	5.9	8.2
C 4752	Volusia silt loam NP treatment, N. Y.	Low	High	Doubtful	Doubtful	6.2	18.8	13	1.7	2.6	1.8
C 4752A	Volusia silt loam NPK treatment, N. Y.	—	—	—	—	6.1	11.2	8	1.9	3.6	2.1
C 4753	Grenada silt loam, Ky.	Low	Med. high	Doubtful	Medium	5.1	13.7	12	3.7	4.4	1.7
C 4754	Maury silt loam, Ky.	High	—	—	—	5.0	28.3	27	6.3	20.7	8.5
C 4755	Houston black clay, Texas	High	No treatment	No treatment	No treatment	7.9	62.4	59	6.0	3.9	1.7
C 4756	Kirvin fine sandy loam, Texas	Low	Good	Medium	Medium	6.3	13.8	9	5.2	2.4	1.3
C 4757	Hagerstown silt loam colluvial, Pa.	Fair	Good	Medium	High	7.7	27.8	17	5.2	7.5	6.4
C 4758	Rayne silt loam, Pa.	Very low	Fair	Medium	High	5.9	22.6	18	5.6	1.7	2.2
C 4759	Colby silt loam, Wisconsin	Excellent	Good	Medium	Medium	6.5	13.0	23	3.0	6.1	4.1
C 4760	Colby silt loam, Wisconsin	Excellent	Good	Medium	Medium	5.4	9.4	16	2.3	4.7	3.9
C 4761	Muscatine silt loam, Ill.	Good	Excellent	Doubtful	Medium	4.9	19.6	13	2.4	5.0	2.1
C 4762	Cisne silt loam, Ill.	Very low	Medium	High	High	4.5	4.0	8	1.6	2.7	1.8
C 4763	Caribou loam, Maine	—	—	High	High	5.2	4.1	7	1.4	0.9	2.8
C 4764	Caribou loam fertilized, Maine	—	—	Medium	Medium	5.2	17.2	7	1.5	2.6	3.9
C 4765	Hartsells fine sandy loam, Ala.	Low	Good	Medium	Medium	4.9	7.1	8	3.4	7.2	6.2
C 4767	Sassafras loam, N. J.	Fair	Poor	High	High	—	33.9	33	9.2	10.0	8.2
C 4768	Sassafras silt loam, N. J.	Fair	Good	Doubtful	Doubtful	—	13.7	8	3.6	3.0	2.3

*As judged by the collector of the sample (1).
†Neutral normal ammonium acetate solution used. Determinations made in 1940 (1).
‡These are index numbers based on a scale of 10. Potash is from weak acid group; phosphorus from dilute strong acid group.

is also an interest in these data in relation to the summary values for soil tests prepared by Morgan.

RESULTS

The Neubauer data are presented in Table 1.[2] Included also are comments concerning native soil fertility, attained soil productivity, certain parts of the summary of soil tests prepared by Morgan, and other data. There is little basis for a mathematical treatment of the relationships involved. However, the data have the qualitative significance usually attached to this kind of work.

Columns 3 and 4 indicate that some of the soils have neen markedly altered by field management, while others show but little evidence of change. The intensive fertilization treatments to which the Merrimac sandy loam had presumably been subjected brought it to a condition where the Neubauer values for phosphorus were nearly as high as were those of the Maury silt loam that had a high native content of this element. The Sassafras loam, rated as being in a poor state of attained productivity, showed a high Neubauer value for potassium (33.8 mgm of K_2O per 100 grams). This value was in accord with the 9.2 composite soil test rating. Recent fertilization may have been responsible for the high value obtained.

The information given here speaks for itself in reflecting diversity of soil, kind of treatment, method of testing, and perhaps period of storage. Those who have had a part in the collaborative soil testing program, can compare these data with their specific laboratory results; to others, it affords opportunity for the comparison of soil test data on diverse soils.

LITERATURE CITED

1. ANDERSON, M. S., KEYES, M. G., and CROMER, G. W. Soluble material of soils in relation to their classification and general fertility. U. S. Dept. Agr. Tech, Bul. 813. 1942.
2. ANONYMOUS. Check soils for collaborative soil testing. Jour. Amer. Soc. Agron., 32:550. 1940.
3. MORGAN, M. F. A comparative study of soil test results by various collaborators on a series of check soils. Minutes of the Sixth Annual Meeting of the Committee on Fertility, American Society of Agronomy, pages 6–21. Mimeographed. 1940.

M. S. ANDERSON AND R. S. HOLMES, *Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture, Beltsville, Maryland.*

[2]The Neubauer data were taken by L. W. Klipp and R. S. Holmes of this Division in 1944.

A CLOVER HULLER FOR HEAD SAMPLES

TO THE writer's knowledge, several efforts have been made toward the development of a clover huller which would be efficient in handling single heads or small lots of clover. Lack of published information indicates that these apparently were not highly successful. Nevertheless, there seems to be a need for such a machine.

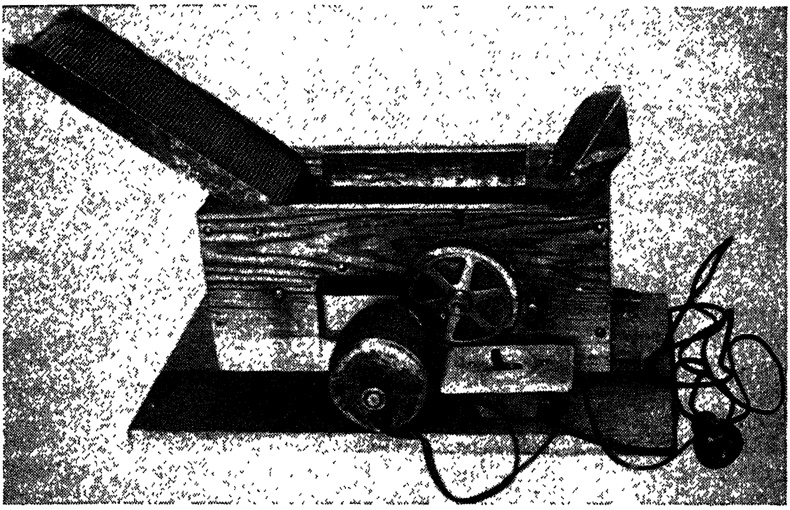

FIG. 1.—Showing assembly of gears and motor.

The machine described and illustrated here (Figs. 1 and 2) works on the principle of rubbing the seed between two pieces of corrugated rubber matting. In this devise, one piece of matting was made into an endless belt by glueing it to a piece of strong canvas with vulcanizing cement. The last corrugation where the ends met was pared down to the bottom of the grooves and the ends sewed down to the canvas at ¼-inch intervals with strong linen thread. This was necessary to prevent the ends from loosening from the canvas. Paring the corrugations off permitted the threads to be recessed so that they wore less rapidly than otherwise. The second piece of matting was merely tacked by the ends to a hinged board.

The endless belt was mounted on two rollers at either end of the machine, one roller the driver covered with emory paper and the other free. Between the rollers a board was mounted with screws

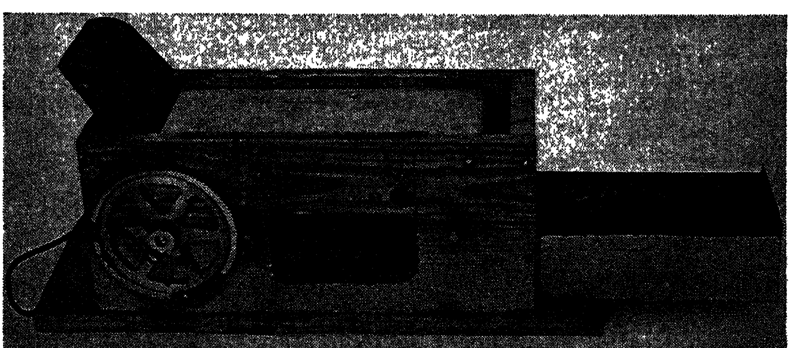

FIG. 2.—Sideboard of frame cut away to expose underside of belt.

with the top on a level with the rollers and beveled underneath so that the ends escaped touching the rollers by about ⅛ inch. This board in turn was covered with light weight sheet metal. The metal was turned over the ends of the board and turned up on the sides to form a "U" in which the belt could run. The sheet metal was tacked to the top of the side boards which housed the balance of the machine.

The corrugations on the belt were worn down slightly so that the grooves would hold seeds so that they projected only slightly above the ridges.

The mounting of the hinged board requires some care. The end into which the clover is fed was beveled slightly to permit easy feeding. The forward end was fitted so that it clears the bottom belt by about 1/64 inch more than the back end. The back or hinged end merely clears the belt so that a sheet of paper can be inserted between the two sections and be withdrawn with a slight pull. It is important that this operation be done carefully to prevent the two sections from rubbing together. The board in the present model has sheet metal strips nailed to the sides which maintain the distances between the two.

The writer was fortunate in obtaining some scrap gears from an old movie projector which were utilized to give the belt the desired speed. Two large gears of about 4¼ inches diameter and two small gears of ⅝ and 1 inch were used and geared to a small motor of about 1/12 horse power. Figs. 1 and 2 show how these were assembled; also, how the sideboards of the frame were cut out in order to expose the underside of the belt for cleaning when seeds are occasionally carried underneath.

The present model carries a 4½ inch belt. This could be narrowed to 3 inches to suit individual needs and equipment available. The overall length is 13 inches with 9 inches between rollers. When fed slowly, this length at present hulls about 80 to 90%, and when remodeled the writer feels that 12 inches between the rollers would give almost 100% hulling once through. No attempt has been made to adapt a screen for cleaning. The seed is caught in a metal pan and screened and cleaned by hand.

The model described has been used exclusively on crimson clover and no scarification of seeds has been noted. To determine its capabilities, a small amount of bur clover was tried with marked success. It is believed that the machine would work with equal efficiency on practically all clovers.—EDWIN JAMES, *Department of Agronomy, University of Georgia, Athens, Ga.*

A TECHNIC FOR MEASURING ERGOT RESISTANCE IN PASPALUM SPECIES[1]

MOST of the *Paspalum* species that grow in the Southeast are susceptible to ergot, *Claviceps paspali*. Dallis grass, *Paspalum*

[1]Cooperative investigations at Tifton, Georgia, of the Division of Forage Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture, the Georgia Coastal Plain Experiment Station, and the Georgia Experiment Station.

dilatatum, the member of this group most widely used in improved pastures is also one of the most susceptible to this disease. In addition to reducing the quality and quantity of viable seed, this ergot may also impair the health of the animals that consume it. Consequently, breeding for resistance to ergot has been one of the principal objectives in the improvement of Dallis grass. Little progress has been made, however, due to the lack of a satisfactory technic for measuring the differences in the amount of ergot in strains of the grass, all of which appear superficially to be equally susceptible to the disease.

The determination of the amount of ergot in the Paspalums is made difficult by the following reactions of the parasite and its host. The initial infection of the florets is marked by the formation of much sticky exudate that usually covers most of the florets in a panicle. Since florets containing normal caryopses may be as heavily covered with exudate as ergotized florets, the presence or absence of exudate is not a satisfactory criterion for determining whether or not a floret is ergotized. Some of the ergots become large enough to spread the lemma and palea apart and may be easily separated. Many of them, however, reach approximately the same size as the caryopses and never spread the lemma and palea apart. These florets may be separated from those containing caryopses only by dissecting all florets in which the glumes are not spread apart by large ergots. This technic is laborious, exceedingly tedious, and time consuming and is not a satisfactory method for analyzing the many seed samples that must be dealt with in a breeding program.

During the past season over 1,000 seed lots of Dallis grass were analyzed for ergot content using the following technic. On August 7, 1943, all seed of the current season was harvested from each of 960 spaced plants of Dallis grass, the constituents of a test of 24 seed sources arranged in four-plant family rows replicated 10 times.

Burton[2] has shown that seasonal variations affect the formation of ergot in Dallis grass. Therefore, in comparing the ergot resistance of different strains of Dallis grass, it is important that the seed for analyses be produced under the same climatic conditions. When dry enough, each seed lot was threshed, screened, and placed in a properly labeled coin envelope. The percentage of heavy florets in each lot of seed was then determined by weighing out a representative 1-gram sample, removing the empty florets with a seed blower,[3] and weighing again the remaining heavy florets. Although these percentages ranged from 47.7 to 70.5 and differed significantly between strains, the information is of doubtful value in measuring ergot resistance. Since in the absence of ergot the percentage of heavy florets in Dallis grass frequently ranges from 20 to 60, it would appear that ergot is not responsible for the formation of empty florets in this grass. Heavy florets, comparable to Dallis grass seed as it goes on the market, would seem, therefore, to be the better base from which to measure

[2]Burton, Glenn W. Factors influencing seed setting in several southern grasses. Jour. Amer. Soc. Agron., 35:465–474. 1943.

[3]Burton, Glenn W. A useful seed blower for the grass breeder. Jour. Amer Soc. Agron., 30:446–448. 1938.

the percentage of ergots in arriving at the ergot resistance of different strains of Dallis grass. The determination of the percentage of heavy florets by weight might well be omitted from future studies where information concerning only the ergot resistance of different strains is desired.

In making the ergot analyses 100 heavy florets were taken from each sample and were placed in 16-mm test tubes. When 20 of these tubes had been prepared, approximately 4 cc of technical 66° sulfuric acid were added to each tube, the tubes placed in a test tube shaker, and shaken for 35 minutes. The caryopses and ergots in the tubes were then washed into beakers of water, separated from the water by pouring the beaker contents thru a fine-mesh screen, and then spread out on properly labeled paper towels to dry. When dry, each sample was rubbed lightly between the fingers to remove the remnants of the lemma and palea and were again blowed to remove this dusty material. The caryopses could then be easily separated from the dark, irregular shaped ergots and counted. These caryopses counts subtracted from 100 gave the percentage of ergotized florets in each sample. (A direct count of the ergots can not be made because some of them are completely destroyed by the acid). Two men working together and counting seed while samples were shaking and drying were able to do 10 to 12 samples per man hour. When compared with the old method of dissecting florets, this technic was much less tiresome, gave more accurate results, and nearly doubled the number of samples that could be analyzed per day.

A statistical analysis of the results of this study revealed that strains of Dallis grass that had appeared to be equally susceptible to ergot were actually significantly different. The mean ergot percentages for the 24 strains (each mean the average of the ergot analyses of 40 plants) ranged from 25.9 to 70.4. A mean difference of 7.5% was required for $P = 0.05$.

This technic has been used with equal success in determining the ergot resistance of strains of *Paspalum notatum* and several Paspalum hybrids. When using this technic with other species, it is necessary to alter the length of the acid treatment to conform with the thickness of the lemma and palea. The thick-glumed florets of common Bahia, for example, must be scarified from 45 to 60 minutes to remove the lemma and palea, while some of the thin-glumed Paspalums require less than half as much scarification.—GLENN W. BURTON, *Coastal Plain Experiment Station, Tifton, Ga.*

BOOK REVIEWS

DE RE RUSTICA (ON AGRICULTURE)

By Lucius Junius Moderatus Columella, translated by H. B. Ash. Loeb Classical Library Series, printed in England but sponsored and sold by the Harvard University Press, Cambridge, Mass., XXIX + 461 pages. 1941. $2.50.

STUDENTS of agricultural history will welcome this book which is printed with the Latin text on one page and the English translation opposite. Numerous footnotes add greatly to its value in research. Translations of the 12 books of Columella's *De Re Rustica* will be published in three volumes; only the first volume containing the first four of the Columella books has thus far been printed. The remaining two are expected to appear after the war.

A considerable number of translations of the works of Columella have been made in various languages including German, French, and Swedish. However, the only one covering the 12 books in English was published in 1745, has been out of print, and has been available to the public only in relatively few libraries.

This modern translation by Ash, written as it is in beautiful English style, should be particularly valuable to teachers of agricultural subjects in schools and colleges. The book provides information whereby the student may readily compare Roman thought with current ideas regarding soils, their management and the adaptation of crops to different environments. It provides an excellent background covering social and economic ideas prevalent in Italy and environs nineteen hundred years ago. This publication, which is being sold at a popular price, should do much to further an appreciation of the work of a great Roman writer who quotes freely from still earlier Roman literature concerned with agriculture and other technical subjects.—M. S. ANDERSON.

ROOT DISEASE FUNGI

By S. D. Garret. Waltham, Mass.: Chronica Botanica Co.; New York: G. E. Stechert & Co. 177 pages, illus. 1944. $4.50.

IN THIS book, the author has done a good job of summarizing, coordinating, and analyzing the numerous individual contributions to the study of root diseases that have appeared in recent years. The book is the first to deal with this group of diseases in such a comprehensive manner. The author's critical analysis of the subject has led to the formulation of a number of broad principles and generalizations that will be helpful to research workers and teachers alike. When such generalizations are made they are printed in italics for emphasis, a feature that increases the usefulness of the book as a reference for workers in related fields.

There is more to the book than the brief title would indicate because its primary emphasis is not upon the fungi which cause root diseases, but rather upon the relationship between these fungi and

the complex environment in which they live. The ecological viewpoint is maintained throughout the discussion. Due recognition is given to the influence of such physical factors as temperature, moisture, texture, reaction, organic content, and plant nutrients on the root diseases. For the convenience of the reader, many well-known root diseases have been tabulated to show at a glance how they are influenced by the various environmental factors. It is recognized that these physical factors do not always exert their influence directly on the fungus and host plant, but indirectly through their effect on the complicated microbiological flora of the soil.

The book is not a purely academic treatise for six chapters are devoted to a discussion of control measures adapted to field crops, plantation crops, and plants grown in greenhouses. The practical agronomist will find much of interest in these chapters.

The book is well written, carefully edited, and remarkably free from typographical errors. It is not extensively illustrated, only 9 figures, mostly line drawings, having been used. A bibliography of over 600 titles, a subject index, and an author index occur at the end of the 148-page text.—J. G. LEACH.

AGRONOMIC AFFAIRS

NEWS ITEMS

DOCTOR CHARLES F. SIMMONS, formerly Extension Agronomist, University of Arkansas College of Agriculture, has accepted a position as Associate Agronomist at the Louisiana Agricultural Experiment Station at Baton Rouge. He will conduct research in the sugarcane area on fertilizers and soil fertility.

—A—

THE LIST of the committee on Soil Tilth given on page 1039 of the December, 1944, number of the JOURNAL should have read as follows: For the American Society of Agronomy, B. T. Shaw, *Chairman*, L. D. Baver, E. N. Fergus, T. M. McCalla, and M. B. Russell; for the American Society of Agricultural Engineers, I. F. Reed, *Chairman*, M. L. Nichols, J. H. Neal, A. P. Yerkes, and E. G. McKibben.

—A—

LT. COL. R. H. MORRISH was incorrectly listed as "Chief of Engineers, U. S. Army" on page 995 of the December, 1944, number of the JOURNAL. His correct title is Chief, Grounds Maintenance Unit, Construction Division, Office of the Chief of Engineers.

—A—

DOCTOR EDWIN B. FRED, a member of the faculty of the University of Wisconsin College of Agriculture since 1913 and Dean of the College since 1943, has been elected President of the University, effective February 15, 1945.

JOURNAL
OF THE
American Society of Agronomy

VOL. 37 MARCH, 1945 NO. 3

TETRAPLOIDS INDUCED IN RICE BY TEMPERATURE AND COLCHICINE TREATMENTS[1]

H. M. BEACHELL AND JENKIN W. JONES[2]

SUCCESS in the artificial production of polyploids in various plant species suggested the desirability of similar experiments with rice. Exposure to extreme and sudden changes in temperature frequently has induced chromosomal aberrations in plants. Matusima (2)[3] reported tetraploid cells in the root tips of rice seedlings exposed for a short time to temperatures of 42.5° to 45.5°C, but he did not say that the plants were tetraploids.

The stage at which chromosomes are most easily affected by environmental changes is thought to be at the time of sporogenesis. In rice, this appears to occur 10 to 15 days prior to heading. At the time of year preceding and during the heading of rice, the maximum daily temperatures are high, and sudden changes in temperature are not uncommon in the rice areas. It is possible, therefore, that such ranges in temperature may be responsible in part for the naturally occurring chromosomal aberrations reported in this paper. The temperature may act directly upon meiosis, resulting in the production of abnormal gametes as reported by Nandi (8); it may cause somatic mutations that eventually affect the germ cells; and immediately following fertilization of the egg cells, the chromosomes may be doubled by cold or heat, and by a combination of both.

All varieties and mutants of rice, *Oryza sativa* L., examined cytologically prior to 1930, were reported to have 12 chromosomes in their pollen mother cells ($2n = 24$). In the past 12 years, however, haploid, trisomic, triploid, and tetraploid plants have been reported and described. In 1931, Morinaga and Fukushima (3) found a haploid among the F_1 plants of an intervarietal cross. Later, Nakamura (5), Ramiah, Parthasarathi, and Ramanujam (9), Jones and Longley (1), and others reported finding haploid rice plants.

In 1932, Nakamori (6) reported the occurrence of trisomic and triploid plants, and in 1933 reported on a tetraploid plant (7). In

[1]Contribution from the Division of Cereal Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture, and the Texas Agricultural Experiment Station, cooperating. Received for publication September 28, 1944.

[2]Associate and Senior Agronomists, respectively.

[3]Numbers in parenthesis refer to "Literature Cited", p. 175.

1936, Morinaga and Fukushima (4) reported finding tetraploid plants in Japan and in 1941 Jones and Longley (1) reported tetraploids in the United States. In the latter paper, the characteristics of haploid, triploid, and tetraploid plants of the Caloro variety were described. The characteristics of these chromosome types also apply to similar chromosomal aberrations found in other rice varieties and hybrids.

Haploid plants have been found in varieties and hybrid populations almost every season during the past 10 years at the Texas Agricultural Experiment Station No. 4, Beaumont, Tex. Haploids probably occur as frequently in varieties as in hybrid material, but plants of the latter are examined in more detail and hence more haploids are found.

Triploid plants also have been observed, but no naturally occurring rice tetraploids have been found at Beaumont. Two tetraploids, one in Blue Rose 41 and the other in Zenith, were found by Dr. C. Roy Adair[4] and the junior author at the Rice Branch Experiment Station, Stuttgart, Ark. Both of these and one of the two Caloro tetraploids reported by Jones and Longley (1) originated as tetraploid-sectors on diploid plants.

In this paper, the production of tetraploid plants by exposing the panicles soon after blooming to low and to high temperatures, to a combination of low and high temperatures, and by soaking the seeds in colchicine solutions at the Texas Agricultural Experiment Station No. 4, Beaumont, Tex., is reported. In the temperature treatments, panicles were exposed at different periods after blooming.

TEMPERATURE TREATMENTS

The effect of low and high temperatures on panicles of Blue Rose rice treated at stages ranging from 5 to 30 hours after blooming was studied in 1939, 1940, and 1941, and the Caloro variety was included in the experiments of the latter 2 years. Panicles on plants growing in the field were treated by immersing them for various lengths of time in thermos bottles containing water varying in temperature from 0° to 4° C for the low temperatures and from 38° to 48° C for the high temperatures. In some treatments, both low and high temperatures were used on the same panicles. Most of the treatments were started 19 to 24 hours after blooming. The period of maximum blooming was recorded daily, and with the exception of a few treatments in 1939, the florets on the panicles treated had bloomed the day preceding or on the day of treatment. All florets blooming earlier or later than this were removed before treatments were made.

The seed produced by treated panicles in 1939 and 1941 was sown directly in rows in the field the following year, but that produced by treatment in 1940 was germinated in pots in the greenhouse and the seedlings transplanted in the field. In 1942, conditions in the field were very unfavorable for germination, survival, and growth.

All tetraploid-like plants obtained from seed produced on the

[4]Associate Agronomist, Division of Cereal Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture, Rice Branch Experiment Station, Stuttgart, Ark.

panicles treated in 1939 were examined cytologically by the late Dr. J. O. Beasley, Texas Agricultural Experiment Station, College Station, Tex., and all proved to be tetraploids. Tetraploid cells were found in all tetraploid-like sectors, and a number of tetraploid plants were isolated by vegetative propagation of the aberrant sectors and also from seeds produced on such sectors. Several of the tetraploid-like plants found in 1940 also were examined cytologically by Dr. Beasley, and all proved to be tetraploids (Fig. 1).

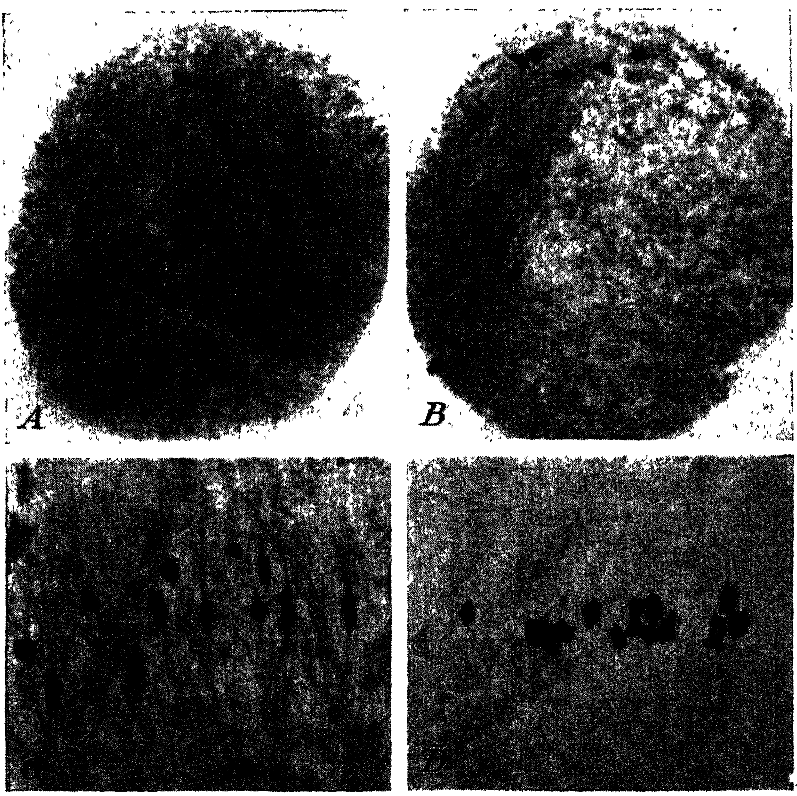

FIG. 1.—Metaphase spindles of pollen mother cells of Blue Rose rice showing (A and B) 12 univalent chromosomes of a haploid plant; (C) showing 12 bivalent chromosomes of a diploid plant; and (D) showing bivalent and tetravalent chromosomes of a tetraploid plant.

The temperature treatments in which tetraploids or other abnormal plants occurred during the 3-year period, 1939–41, are given in Table 1 and are summarized in Table 2.

Other low and high temperature treatments were tried, but since no tetraploid plants were observed, the treatments are not shown in Table 1.

A total of 255 panicles were treated in the 3-year period and 8,828 seeds were produced from which 4,794 plants were obtained. Of these

TABLE 1.—*Tetraploid and other abnormal rice plants obtained from panicles treated with low and with high temperatures, or a combination of both, shortly after blooming.*

Variety	Length of treatment, min.		Time after pollination that treatment began, hours	Temperatures, °C		Number of										
						Panicles treated	Florets		Plant obtained							
	Low	High		Low	High		Fertile	Sterile	Total	Tetraploid	Tetraploid-sector	Haploid	Sterile type	Non-head	Severe white-tip
Low Temperature Treatments															
Blue Rose	97, 62	—	(19 & 20)	0–4	—	2	95	6	86	9	0	0	0	0	0
Blue Rose	120, 165	—	(24 & 30)	0–4	—	4	108	18	94	2	0	0	1	0	4
Blue Rose	240	—	8	0–4	—	3	81	21	74	0	1	0	0	0	0
Blue Rose	240, 195	—	(8 & 24)	0–4	—	2	64	29	42	1	0	0	0	0	0
Caloro....	40	—	21	0–4	—	4	68	61	24	1	0	0	0	0	0
Caloro....	320	—	22	0–4	—	4	64	84	8	1	0	0	0	0	0
Blue Rose	20	—	20	0–4	—	3	81	34	46	1	0	0	0	0	0
Blue Rose	40	—	20	0–4	—	3	114	24	71	1	0	0	0	0	0
Blue Rose	320	—	20	0–4	—	3	124	30	78	1	0	0	0	0	0
Total...						28	799	307	523	17	1	0	1	0	4

						High Temperature Treatments									
Blue Rose	—	15	24	—	44	1	152	—	85	0	1	0	0	0	0
Blue Rose	—	30	22	—	40	2	334	—	180	0	0	1	0	0	0
Blue Rose	—	45	22	—	44	2	694	—	365	1	1	0	0	0	0
Blue Rose	—	90	24	—	40	1	275	—	129	0	0	0	0	0	0
Caloro....	—	160	21	—	38	4	115	9	56	0	0	0	1	0	0
Caloro....	—	80	21	—	40	4	103	12	31	1	0	0	0	0	0
Total...						14	1,673	—	846	2	3	1	1	0	0
						Low and High Temperature Treatments in Succession									
Blue Rose	15	15	20	0–4	40	1	43	—	17	3	0	0	0	0	0
Blue Rose	15	15	24	0–4	44	1	109	—	65	0	1	0	0	0	0
Blue Rose	15	15	21	0–4	45	2	64	—	47	0	1	0	0	0	0
Caloro....	10	10	20	0–4	42	3	117	26	47	0	0	0	0	1	0
Blue Rose	20	20	20	0–4	40	2	24	62	17	1	0	0	0	0	0
Blue Rose	40	40	20	0–4	40	2	70	58	44	2	1	0	0	0	0
Blue Rose	40	40	20	0–4	42	3	99	18	44	1	1	0	0	0	0
Total...						14	526	—	281	7	4	0	1	1	0
Grand total..........						56	2,998	—	1,650	26	8	1	2	1	4

TABLE 2.—*Summary of rice panicles treated with low and with high temperatures, or a combination of both, for the 3-year period, 1939–41.*

Year treated	Variety	Number of										
		Panicles	Florets		Plants obtained							
			Fertile	Sterile	Total	Tetraploid	Tetraploid sector	Haploid	Sterile type	Non-head	Severe white-tip
1939	Blue Rose	24	3,902	——	2,185	4	4	1	0	0	0
1940	Blue Rose	52	1,045	1,079	797	12	2	0	1	0	4
1940	Caloro	18	103	172	48	0	0	0	0	0	0
1941	Blue Rose	75	1,907	1,418	1,022	7	2	0	0	0	0
1941	Caloro	86	1,971	1,025	742	3	0	0	1	1	0
Total...........		255	8,828	——	4,794	26	8	1	2	1	4

plants, 26 were tetraploids, 8 tetraploid-sectors, 1 haploid, 2 highly sterile, 1 produced no heads, and 4 were severely affected by white-tip. The highly sterile, nonheading, and white-tip plants may or may not have resulted from the treatments. It is reasonable to conclude, however, that the tetraploid and tetraploid-sector plants were produced by the temperature treatments, since no tetraploids have been observed in the untreated material of either of these varieties at Beaumont. In many treatments, no tetraploid or other abnormal plants were obtained, probably due to the fact that the fertilized egg cells were not in the proper stage to be affected at time of treatment.

Low temperature treatments were more effective than high temperatures in producing tetraploids. Of the 523 plants grown from seed produced on panicles treated with low temperatures, 17 were tetraploid and 1 a tetraploid-sector plant. Of the 248 plants grown from seed of panicles treated in succession with low and high temperatures, 7 were tetraploid and 4 were tetraploid-sector plants. On the other hand, of the 846 plants grown from seed of panicles treated with high temperatures alone, only 2 were tetraploid and 3 were tetraploid-sector plants. Tetraploids were obtained from both short and long periods of treatment (Figs. 2 and 3).

Most of the tetraploid and tetraploid-sector plants were obtained from treatments begun 19 to 24 hours after blooming. This indicates that under field conditions the egg cells were apparently fertilized during this period, for it is assumed that chromosome doubling is most easily induced in the early stage of the embryo. The tetraploid-sector plants probably resulted from treatments of egg cells that had passed through the first division of the embryo.

It is believed that had the seed obtained from panicles treated in 1939 and 1941 been germinated and the seedlings grown under more favorable conditions, probably other tetraploid plants would have survived, for under normal conditions only from 50 to 60% of the

diploid seed sown produce plants that survive and reach maturity. Therefore, since $4n$ rice seeds usually do not germinate as well as those of $2n$ plants, it seems reasonable to assume that a higher seed and seedling mortality rate prevails in tetraploids than in diploids.

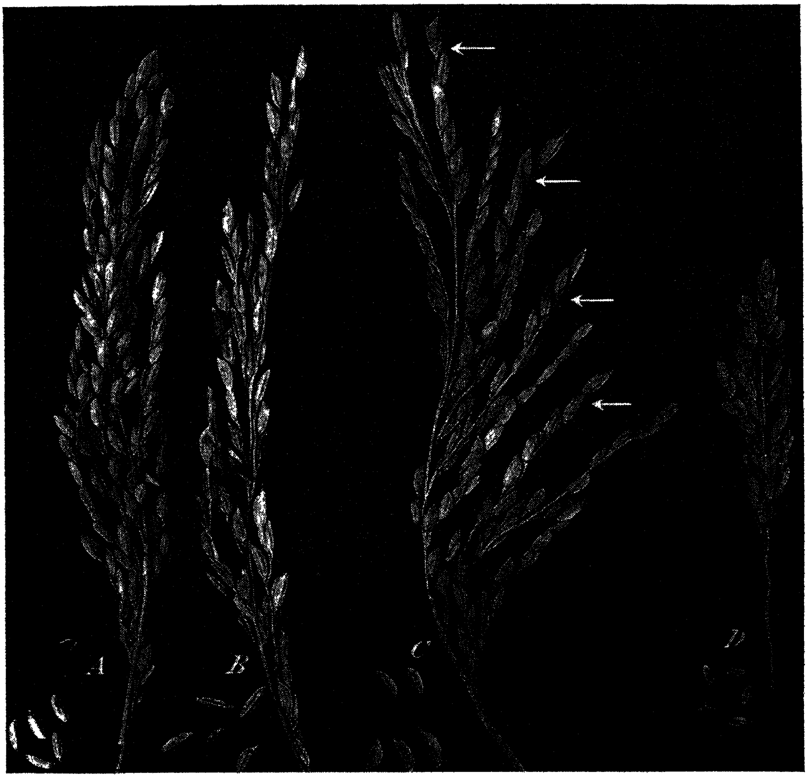

FIG. 2.—Panicles and seeds or florets of diploid (A), tetraploid (B), tetraploid-sector (C), and haploid (D) Blue Rose plants. Arrows point to tetraploid-sectors.

Temperatures of 44° C or above were highly injurious to the setting of seed. In 1940, 527, and in 1941, 210 Blue Rose florets on panicles were treated for 10 to 20 minutes at 48° and 46° C, respectively. No seeds developed following treatment at the higher temperature, and only 88 seeds set at the lower temperature, or 41.9% of the florets treated; whereas, the average seed set on all Blue Rose panicles treated at temperatures below 44° C in 1940 and 1941 was 49.6 and 57.1%, respectively.

The higher temperatures also caused a great reduction in the viability of the seeds obtained. In 1940, of 137 Caloro and Blue Rose seeds from panicles treated 30 minutes or more at 45° C or above, only 31 seeds, or 22.6%, germinated; whereas, the average germination under favorable conditions for all seeds from the 1940 treatments

was 73.6%. In 1941, of 88 seeds set on Blue Rose panicles treated for 10 to 20 minutes at 46° C, only 21, or 23.9%, produced plants. In the same year under field conditions, 379 seeds of Caloro and Blue

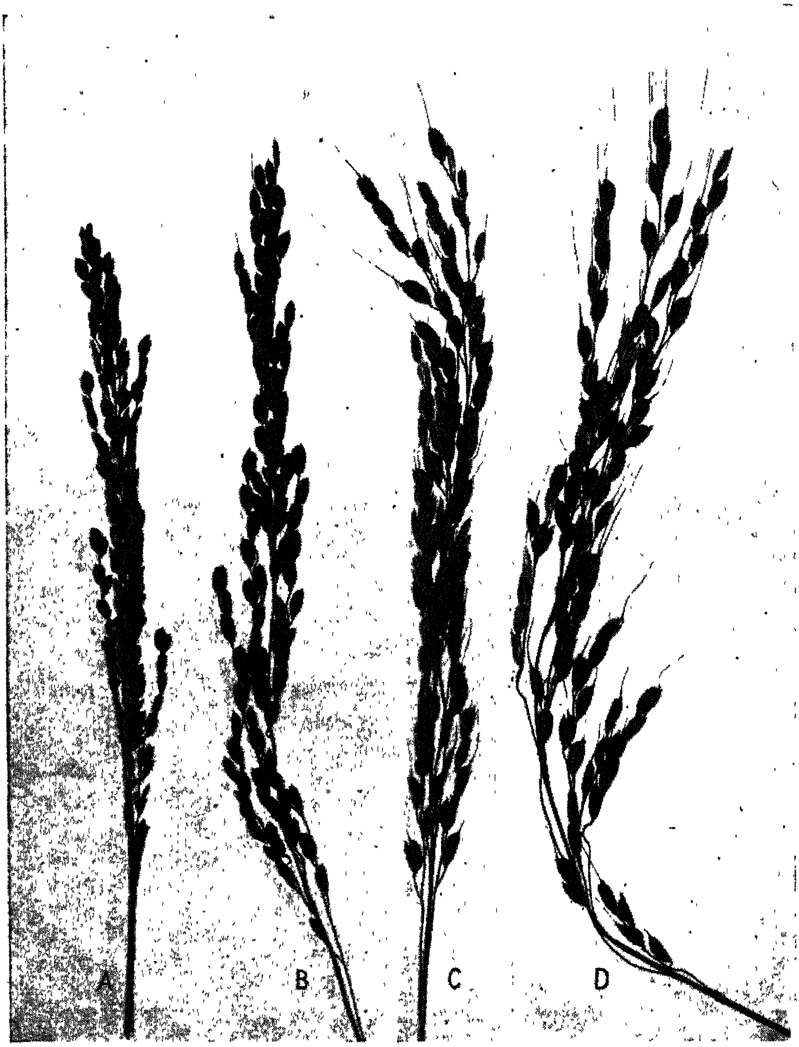

FIG. 3.—Panicles of haploid (A), diploid (B), triploid (C), and tetraploid (D) Caloro plants.

Rose from panicles treated for 20 minutes or more at 44° C or above, 119 seeds, or 31.4% produced plants; whereas, the average germination of seed for all 1941 treatments was 45.6%. However, all of the plants obtained from seed of panicles exposed to these treatments were normal. The seeds that failed to germinate were not examined

for the presence or absence of embryos, but it is possible that in some cases the embryo might have been absent, as reported by Randolph (10) in corn.

COLCHICINE TREATMENTS

In the spring of 1939, lots of 10 to 15 seeds of Blue Rose, Caloro, Fortuna, and Rexoro varieties were soaked at room temperatures or lower in colchicine solutions varying in strength from 0.0125 to 0.05%. Seeds that had not germinated and those with shoots as much as 20 mm in length were used. The seeds were soaked 2 to 240 hours. A large number of the seeds treated after sprouting produced thickened shoots and roots, indicating chromosomal aberrations. The seedlings that survived treatment were transplanted in the field and when the plants headed they were examined carefully for tetraploid seeds, but none was observed. The following year, all seeds from these plants were sown rather thinly in rows 1 foot apart and three tetraploid Blue Rose plants were found, but there were none among the Caloro, Fortuna, or Rexoro varieties. These Blue Rose tetraploids apparently originated as a result of the colchicine treatments.

Different shoots of a haploid plant were soaked in 0.18% colchicine solution for 0, 2, 4, 21, 46, and 94 hours, respectively, involving a total of 28 shoots. The crown of each shoot which was about 6 inches in length was split before treating and trimmed to about 1½ inches after treating. The shoots were maintained in a culture solution for 30 days after treating, but when they were transferred to soil, all but four died. The surviving shoots included two untreated, one soaked 4 hours, and one soaked 94 hours. The *untreated* shoots gave *diploid* plants, and the treated shoots plants with *diploid-sectors* on which one or more seeds were produced, and from these seeds diploid plants were obtained. In both cases the plants of later generations appeared to be identical in appearance. During the winter of 1940–41, shoots of the same haploid were again treated in a colchicine solution and another diploid-sector shoot was obtained. These results indicate that this particular haploid probably had a tendency to revert to the diploid form, and it is not certain that the colchicine solution had any effect.

Two diploid-sector shoots on haploid plants that occurred naturally have been observed at Beaumont, one during the winter of 1940–41 and the other during the winter of 1942–43. The diploid-sectors were separated from the haploid shoots and diploid plants with no evidence of haploid tissue were obtained.

A gold-hulled haploid plant from the cross Rexoro × Kameji, on which four seeds were produced, was found in 1939. These seeds gave plants that were diploids, one of which had straw-colored hulls, probably resulting from an outcross.

In the winter of 1941–42, two seeds were produced on a Calady haploid plant grown in the greenhouse at Beltsville, Md. These seeds produced diploid plants similar in appearance to Calady.

GROWTH CHARACTERISTICS OF CHROMOSOME GROUPS

In 1941, the growth habits of tetraploid, diploid, and haploid plants of the Blue Rose and Caloro varieties were studied at Beaumont.

From plants of each chromosome type grown in the greenhouse during the winter, single shoots were transplanted in the field on May 27. A total of 11 to 23 shoots of each type was grown in rows 1 foot apart with the plants spaced 12 inches apart. The data recorded are given in Table 3.

TABLE 3.—*Effect of chromosome number on vegetative and seed characters of rice in 1941 at Beaumont, Tex.*

Chromosome group	Number of plants	Date first headed	Plant height, in.	Panicle length, cm	Average per plant, number			Fertile florets, %	Seed length, cm*	Seed width, cm*
					Culms	Florets	Seeds			
Blue Rose										
Diploid (2*n*)...	20	Sept. 2	47.1	21.3	5.9	158	128	81.0	0.78	0.34
Tetraploid (4*n*)	13	Sept. 6	40.0	21.3	2.0	57	7.7	13.5	0.97	0.40
Triploid (3*n*)...	15	Sept. 5	46.1	23.8	3.4	130	0.8	0.6	0.91	0.40
Haploid (1*n*)...	11	Sept. 3	32.5	—	6.4	—	0	0	—	—
Caloro										
Diploid (2*n*)...	23	Aug. 20	44.7	22.0	7.3	153	131	85.6	0.67	0.36
Tetraploid (4*n*)	20	Aug. 26	38.1	22.9	2.2	65	7.3	11.2	0.80	0.41
Triploid (3*n*)...	23	Aug. 21	42.3	24.2	3.5	124	0.4	0.3	0.87	0.40
Haploid (1*n*)...	23	Aug. 22	30.5	15.0	11.3	171	0	0	0.55	0.30†

*Measurements based on 10 seeds per plant where available; otherwise on the number of seeds available.
†Ten florets measured from each plant.

The tetraploid and triploid plants are not readily distinguishable from diploid plants in the early stage of growth. Later in the season, however, tetraploid plants develop rather thick coarse leaves of darker green color than those of diploid plants. The Blue Rose and Caloro tetraploids do not tiller well at Beaumont, rarely producing more than two culms per plant (Table 3). The tetraploids also headed several days later, were shorter in stature, had coarser seeds with heavier glumes (often awned), and a much lower fertility than diploid plants of these varieties. The triploid plants did not tiller so well, headed somewhat later, were slightly shorter, and had much coarser florets than the diploid plants. Except for an occasional seed, the triploids were entirely sterile.

All organs of the haploid plants were much reduced in size as compared to diploid plants of the same varieties, and while the plants tillered well, they were entirely sterile.

SUMMARY

Naturally occurring haploid and triploid plants that arose as mutations in varieties and hybrids at the Texas Agricultural Experiment Station No. 4, Beaumont, Tex., are reported.

Twenty-six tetraploid and eight tetraploid-sector plants were obtained from seed produced on panicles of the Blue Rose and Caloro

varieties exposed, for certain periods, to low and high temperatures or a combination of both within 19 to 24 hours after blooming.

Soaking Blue Rose seed in colchicine solutions produced three tetraploid plants in the second generation following treatment.

Shoots of a haploid plant, *untreated* and treated in colchicine solutions, produced diploid and diploid-sector plants. Three cases in which haploid plants produced some seed are reported.

Tetraploid and triploid Blue Rose and Caloro plants were not as tall, tillered less, were less fertile, and had coarser leaves and larger florets and seeds than diploid plants of these varieties; whereas, the haploid plants were completely sterile and were shorter, tillered much more, and had finer leaves and culms and smaller florets than the diploids.

LITERATURE CITED

1. JONES, JENKIN W., and LONGLEY, A. E. Sterility and aberrant chromosome numbers in Caloro and other varieties of rice. Jour. Agr. Res., 62:381–399. 1941.
2. MATUSIMA, K. Chromosome doubling in the rice plants treated with high temperatures. Jap. Jour. Gen., 11:235–237. 1935. (In Japanese.)
3. MORINAGA, T., and FUKUSHIMA, EIJI. Preliminary report on the haploid plant of rice, *Oryza sativa* L. Imp. Acad. Japan Proc., 7:383–384. 1931.
4. ———. [Observations on the autotetraploid rice plants] (Preliminary note). Jap. Jour. Gen., 12:59. 1936. (In Japanese.)
5. NAKAMURA, SEISUKE. [Haploid plants in rice]. Jap. Jour. Gen., 8:223–227. 1933. (In Japanese.)
6. NAKAMORI, EIITI. On the appearance of the triploid plant of rice, *Oryza sativa* L. Imp. Acad. Japan Proc., 8:528–529. 1932.
7. ———. On the occurrence of the tetraploid plant of rice, *Oryza sativa* L. Imp. Acad. Japan Proc., 9:340–341. 1933.
8. NANDI, H. K. Effect of temperature on the formation of diploid gametes in *Oryza sativa* L. 24th Indian Sci. Cong., Hyderabad, Proc., 1937:268. 1937.
9. RAMIAH, K., PARTHASARATHI, N., and RAMANUJAM, S. Haploid plant in rice (*Oryza sativa* L.) Current Sci. (India), 2:170–171. 1933.
10. RANDOLPH, L. F. Some effects of high temperature on polyploidy and other variations in maize. Proc. Nat. Acad. Sci., 18:222–229. 1932.

HYBRID POPCORN[1]

ARTHUR M. BRUNSON AND GLENN M. SMITH[2]

ALTHOUGH frequently referred to in wartime as a nonessential or semi-luxury crop, popcorn is in reality one of the most efficient sources of human food in terms of usable calories produced per acre. It can be stored cheaply for a period of years and is easily processed for final consumption. Popcorn has long been a popular food and confection in the United States, both for home popping and as sold by vendors. During the past 2 or 3 years consumption has increased very appreciably.

During recent years the acreage devoted to producing the crop in the United States has fluctuated, in round numbers, between 50,000 and 100,000 acres per year, or approximately 0.1% of the total corn acreage of the country. Most of the commercial popcorn is grown in the Corn Belt, with by far the largest center of production located in western Iowa.

Because of the overshadowing importance of dent corn in the agricultural economy of the country, the possibilities of improving popcorn have been somewhat neglected by plant breeders. The same principles and technics used in hybrid dent corn breeding are applicable, however, and equal opportunities exist to improve yield and standing ability, with the added opportunities to improve popping expansion, flavor, and tenderness. It is the purpose of this paper to report on some of the breeding work in progress and to present performance data of certain popcorn hybrids now in actual production.

CHARACTERS CONSIDERED

In a popcorn breeding project the interests of both the producer and consumer must be considered. Producers are primarily interested in yield and standing ability, while the consumers main interest is popping expansion and quality. The characters considered below have been grouped into these two categories.

PRODUCER'S CHARACTERS

Yield.—As in dent corn, it has been found possible to produce popcorn hybrids that materially outyield the better strains of open-pollinated varieties. Yields of popcorn ordinarily are reported in pounds of ear corn per acre rather than in bushels per acre.

Standing ability.—Almost equally as important as yield from the producer's standpoint is the ability of the crop to stand well until harvest. This is particularly important with popcorn because of the

[1]Contribution from the Division of Cereal Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture; Department of Agronomy, Kansas Agricultural Experiment Station, Manhattan, Kans.; and Department of Botany and Plant Pathology, Purdue University Agricultural Experiment Station, Lafayette, Ind. Journal paper no. 185 of the Purdue University Agricultural Experiment Station. Received for publication October 27, 1944.

[2]Senior Agronomist and Associate Agronomist, respectively, Bureau of Plant Industry, Soils, and Agricultural Engineering, Lafayette, Ind.

almost universal use of mechanical pickers with this crop, and because of the serious effect on quality when ears lie on the ground. Stalks which lean 30° or more, or are broken below the ear at harvest time, are reported as lodged.

Resistance to disease and insects.—In addition to the usual hazards to the corn crop in general, diseases and insects are of particular importance to popcorn because of their effect on the quality of the crop. They not only reduce yield but also lower popping expansion and introduce off-flavors. Ear rots and stalk rots are probably most important of the diseases; European corn borer and corn ear worm of the insects. No outstanding disease and insect resistance differences between the hybrids and the open-pollinated varieties have been noted, but in these respects all hybrids reported in this paper are at least as good as the varieties in trials to date.

CONSUMER'S CHARACTERS

Popping expansion.—Popping expansion is of the utmost importance to the vendor or large commercial popper. The term refers to the volume of popped corn obtained from a unit volume of unpopped corn and is expressed as the volume ratio of popped to unpopped corn. An expansion of 18–20 is considered fair, 21–26 good, and 27 or above excellent. Popcorn purchased at grocery stores usually shows an expansion of 20 or below.

The details of the method used in determining the expansion of popcorn vary with different growers and manufacturers, causing considerable confusion in the trade. Differences may be due to the method of popping the corn, the shape and size of the containers, the degree of packing the popped corn before reading the volume, and to other variables. In order to establish a standard means of comparing different samples, the machine shown in Fig. 1 was designed and installed at the Purdue University Agricultural Experiment Station. It consists of a small commercial electric popper mounted on a metal frame. The popper empties into a sheet metal hopper which leads to a metal tube 4 inches in diameter and 42 inches long, directly underneath. This tube has a 2-inch glass window, so calibrated that the volume of the popped corn may be read directly in expansion units. In making a popping test the popper is first brought to operating temperature, a 200 cc sample of "raw" corn is placed in the popper, the stirring mechanism started, and 20 cc of popcorn dressing added. Popping begins in approximately 1 minute and is allowed to continue until it ceases. The corn is then dumped into the hopper, falls into the tube, and the expansion is read directly from figures on the glass window. For small quantities, and especially for testing individual ears, a 25-cc sample is used. In order to avoid overheating with small samples, a variable transformer is introduced into the line leading to the heating element of the popper. The smaller sample also requires the use of a smaller measuring tube and a reducing funnel over the hopper opening.

Tenderness.—Fortunately this character tends to accompany high expansion. Tastes vary, but most people prefer the more tender types which "melt in the mouth." In the more desirable types not

only is the main portion of the popped kernel tender but there is an absence of hard core at the base.

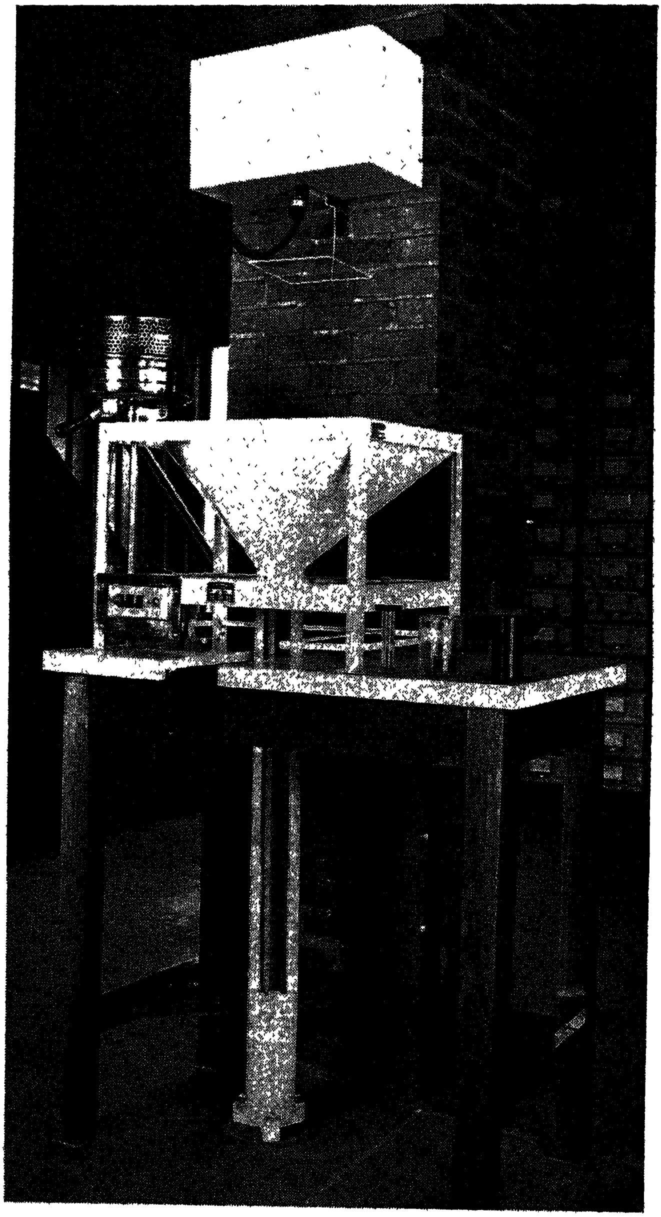

FIG. 1.—Experimental popper used in determining popping expansion of samples in popcorn breeding project.

Hulls.—Closely associated with tenderness in the popular mind is the absence of objectionable hulls. The so-called "hulless" varieties are not actually hulless but have a thin tender hull which readily disintegrates in the mouth.

Flavor.—There is a surprising variation in flavor of various strains of popcorn when eaten without seasoning. There is a range from those with no flavor at all to those with a distinctly sweet pleasant flavor on one hand, or to those with a strong disagreeable flavor on the other hand. By selection of inbred lines it is possible to eliminate undesirable flavors from resulting hybrids.

Kernel shape.—Popped kernels may be of two general shapes, *viz.*, the mushroom type which puffs up to a distinctly globular form, and the butterfly type which turns inside out when it explodes. A considerable proportion of the globular or mushroom kernels in popped samples is characteristic of the South American variety and of hybrids which have originated from it.

Color.—All yellow popcorn when popped is distinctly cream colored compared to the chalky white of white varieties. In addition to this diffused endosperm color, some strains have a distinct flecking or mottling of deep yellow on the outside of the popped kernels. This character is usually most pronounced in strains which tend to have a mushroom kernel. Inbred lines and the hybrids produced from them differ widely in the amount of mottling on the popped kernels.

PREVIOUS WORK

In 1935, the Minnesota Agricultural Experiment Station introduced the first commercial hybrid popcorn. This hybrid, Minhybrid 250, a small-kerneled, small-eared variety of the white hulless type, was reported to have 16% higher yield and 29% higher popping expansion than the open-pollinated Hulless used as a check. Its adaptation seems to be limited to the northern edge of the Corn Belt. In the main popcorn-producing area it is unsatisfactory in yield and standing ability, and never has been widely popular.

CURRENT INVESTIGATIONS

A number of lines of yellow popcorn in the early stages of inbreeding were brought from Arlington, Va., to Manhattan, Kans., in 1925 by J. G. Willier, then with the Bureau of Plant Industry. Further inbreeding and trial crossing gave hybrids with outstanding advantages in yield and lodging resistance but of very mediocre quality. The original inbred lines were discarded and a fresh start made with material carefully selected for good quality and high popping expansion.

Supergold, a yellow pearl variety, mass-selected for high expansion over a period of several years by the Kansas Agricultural Experiment Station in cooperation with the Bureau of Plant Industry, Soils, and Agricultural Engineering, and an especially good strain of South American grown by H. W. Spear of Olathe, Kans., were used as the foundation material. In each case a large number of ears, field-selected

from the standing plants in the fall, were popped individually and only a few of the best saved for starting inbred lines. During the first few years of inbreeding these lines were further selected on the basis of popping tests as well as for general agronomic characters. After 4 years of inbreeding, trial crosses indicated that some very promising hybrids were possible on the basis of both field performance and quality of the produce.

The above work was carried on at the Kansas Agricultural Experiment Station cooperating with the Bureau of Plant Industry, Soils, and Agricultural Engineering, at Manhattan, Kans., where the severe droughts of 1930–36 seriously retarded the progress of the breeding project. In 1938, the material was brought to Lafayette, Ind., where the trials reported below have been carried on cooperatively by the Purdue University Agricultural Experiment Station and the U. S. Dept. of Agriculture. Performance trials of all possible combinations of groups of inbred lines have eliminated many lines so that commercial production at the present time is based on only four Supergold lines, Sg16, Sg18, Sg30A, and Sg32, and one South American line, SA24. The hybrids for which the data below are given are all produced from these five inbred lines. Hybrids numbered from 1 to 6 are single crosses involving one Supergold and one South American line; those numbered from 20 to 23 are single crosses involving two Supergold lines; and those numbered 31 to 38 are three-way crosses. Pedigrees of hybrids for which performance data are given are as follows:

Purdue 1 or K-1*	Sg16 × SA24
Purdue 2 or K-2*	Sg18 × SA24
Purdue 3	Sg32 × SA24
Purdue 6 or K-3*	Sg30A × SA24
Purdue 20	Sg30A × Sg18
Purdue 22	Sg16 × Sg18
Purdue 23	Sg32 × Sg18
Purdue 31	(Sg16 × Sg18) × SA24
Purdue 32 or K-4*	(Sg30A × Sg18) × SA24
Purdue 38	(Sg32 × Sg16) × SA24

*Designations used by the Kansas Agricultural Experiment Station.

The Purdue popcorn hybrids in commercial production at the present time are all single crosses or three-way crosses. This is more feasible with popcorn than with dent corn, since popcorn inbred lines are relatively more vigorous and easier to propagate than those of dent corn and because seed grading problems of popcorn single crosses are less troublesome than with dent corn. Of the original South American inbred lines, all except SA24 have been discarded because of mediocre quality. A new group of South American inbreds from highly selected material is being tested at the present time with very promising results to date. It seems likely that double crosses will

eventually supplant single and three-way crosses when satisfactory combinations have been obtained because of greater economy of seed production.

PERFORMANCE TRIALS

Of the many popcorn hybrids tested, the performance trials of those in commercial production and two others showing distinct promise are summarized in Table 1. The results shown were obtained on moderately productive land at Lafayette, Ind., during the unusually favorable seasons of 1941–43. Five replications of 2 × 10 hill plots spaced 36 × 36 inches were used. The fertilizer treatment consisted of 150 pounds per acre of 0–12–12 fertilizer drilled in the row at planting time. The plots were all thinned to a uniform stand of two plants per hill. Harvesting was done late each year, at which time the corn was uniformly dried nearly to, or entirely to, popping condition.

At harvest time representative ear samples were saved from each plot and hung in onion bags in an untreated, well-ventilated attic until they had reached optimum popping condition. (Too rapid drying in mechanical driers may impair the popping quality.) The samples were then shelled and duplicate popping trials run on each sample.

TABLE 1.—*Performance trials of Purdue popcorn hybrids at Lafayette, Ind., 1941–43.*

Hybrid or open-pollinated variety	Acre yield of ear corn, lbs.				Popping expansion				Rank based on		Lodged plants, %	Av. wt. per ear, oz.
	1941	1942	1943	Average	1941	1942	1943	Average	Yield	Expansion		
Purdue 1	3,170	5,075	3,800	4,015	28.2	28.5	28.5	28.4	2	2	10	4.1
Purdue 2	2,905	4,755	—	3,830*	30.5	30.5	30.5	30.5	4	1	6	4.0
Purdue 3	3,000	5,050	3,940	3,997	25.5	25.0	25.0	25.2	3	4	7	4.4
Purdue 6	2,515	5,245	5,075	4,278	27.0	27.0	27.0	27.0	1	3	5	4.3
South American	2,080	3,095	2,575	2,583	23.0	23.5	23.0	23.2	5	5	25	3.0
Sig. dif.	633	526	620									
Purdue 31	4,330	5,000	4,440	4,590	27.0	27.0	27.0	27.0	2	1	4	3.8
Purdue 32	3,605	4,390	3,865	3,953	25.5	26.0	26.0	25.8	3	2	3	4.2
Purdue 38	4,720	4,660	4,590	4,657	25.5	25.0	25.0	25.2	1	3	4	3.9
South American	2,755	2,975	2,575	2,768	23.0	23.5	23.0	23.2	4	4	25	3.0
Sig. dif.	631	383	620									
Purdue 20	3,195	3,660	3,425	3,427	32.7	33.0	32.5	32.7	3	1	6	2.9
Purdue 22	3,945	4,195	3,985	4,042	30.5	30.0	30.0	30.2	1	2	9	2.8
Purdue 23	3,750	4,145	3,530	3,808	28.2	28.0	28.0	28.1	2	3	11	3.2
Supergold	3,035	3,465	2,850	3,117	28.0	27.5	27.5	27.7	4	4	18	2.7
Sig. dif.	474	286	620									

*Based on 2-year average.

All the hybrids reported in Table 1 yielded more than the open-pollinated varieties with which they were compared in each of the 3 years tested. Average yield increases of the hybrids for the 3-year period ranged from 9 to 68%. Field performance of the hybrids in actual commercial production in many localities has confirmed these indications of high-yielding ability. By far the best yields have been obtained in hybrids between Supergold and South American parents. Neither pure Supergold nor pure South American hybrids have been found which possess the vigor or yielding capacity of hybrids from inbreds of both varieties. In the production of such hybrids, the Supergold inbred lines or single crosses must be used as the seed parents and the South American lines or single crosses as the pollen parents, since fertilization will not take place if the reciprocal is attempted.

All of the hybrids also stood better at harvest time than the open-pollinated varieties. It happened that there was very little lodging at Lafayette during the years of these trials, but reports from commercial producers indicate that most of these hybrids stand very well even under rather severe conditions.

The hybrids reported in Table 1 all have better popping expansions than the corresponding open-pollinated strains used in the trials and are very appreciably better than the average run of yellow popcorn on the market. The trade has been quick to appreciate the advantages of superior popability and in a number of cases dealers have been willing to pay a premium for popping corn of the better hybrids.

PRODUCTION OF HYBRID SEED

The inbred lines used in these hybrids have not been released and no inbred seed is available to individuals at the present time. In 1940 and 1941 small isolated detasseled seed plots were produced by the Purdue University Agricultural Experiment Station to provide seed for more extensive tests under field conditions. Beginning with 1942, commercial seed of Purdue popcorn hybrids has been produced by the Agricultural Alumni Seed Improvement Association, Lafayette, Ind., a nonprofit organization acting as agent of the Purdue University Agricultural Experiment Station. In addition, the Kansas Agricultural Experiment Station has produced some

TABLE 2.—*Hybrid popcorn seed production, 1940–44.*

Year	Pounds seed produced			
	Purdue Agr. Exp. Sta.	Agr. Alumni Seed Imp. Assoc.	Kansas Agr. Exp. Sta.	Total
1940	1,900	....	....	1,900
1941	5,700	....	....	5,700
1942	....	16,000	350	16,350
1943	....	53,000	1,150	54,150
1944	....	About 150,000	About 10,000	About 160,000

commercial hybrid popcorn seed during the past 3 years. A record of total seed production to date is given in Table 2.

Even though seed production has been approximately trebled every year, the demand has outrun the supply each year to date. The amount of seed required to plant an acre depends on the kernel size of the seed parent, but will average about 4 pounds. On this basis it can be seen that Purdue hybrids already represent an appreciable proportion of the popcorn acreage of the country.

FREQUENCY OF ABORTED POLLEN GRAINS AND MICROCYTES IN GUAYULE, *PARTHENIUM ARGENTATUM* GRAY[1]

LEROY POWERS AND ELDON J. GARDNER[2]

USUALLY considerably less than 50% of the commercial seed of guayule is viable. Hence, any information pertaining to the causes for this comparatively low percentage of viable seed is of value in breeding this crop. For that reason, studies on the percentage of aborted pollen grains and frequency of microcytes (for definition of term see Belling and Blakeslee (1)[3]) were made for collections of guayule, *Parthenium argentatum* Gray. Since the collections reproducing apomictically are pseudogamous (5), the information derived from such studies should facilitate the improvement of these forms also.

MATERIAL AND METHODS

The collections employed in this study were grown from seed obtained from natural populations growing in Mexico and the Trans-Pecos Area of Texas. The Mexico collections were made by Powers and those from the Trans-Pecos Region by Powers and Federer. The commercial varieties were grown from seed taken from the same lots as those used in planting the commercial fields. The empty pollen grains and those showing definite disintegration of the cytoplasm were classed as aborted. Pollen grains having diameters less than 13.6 microns were classed as microcytes. In the case of aborted pollen the frequency recorded was the number in 100 full-size pollen grains per plant and hence is the percentage also; whereas, the microcytes recorded are the number among these same 100 full-size pollen grains and therefore are not a percentage.

In staining the pollen for classification as to aborted pollen grains and microcytes, Watkin's cotton blue-lacto-phenol method as given by Lee (3) was used.

The seed was planted in the greenhouse February 11, 1943, "spotted out" March 8, and transplanted into the field at Salinas, Calif., on June 8 of the same year. After "spotting out" there were 72 plants per standard greenhouse flat. The design of the experiment was the same for greenhouse and field and was a 7×7 lattice squared with $K + 1$ replicates. Hence, there were 49 variates and 8 replicates. Four of the 49 variates were duplicates. The individual plot was 4 plants by 3 plants, making a total of 12 plants per plot. One hundred pollen grains were examined per plant and the pollen was collected on the basis of replications so as to control any differences due to time of collection. The plants in the field were spaced 4 feet apart in the rows and the rows were 4 feet apart.

The analysis of variance was used in analyzing the data for testing significance of differences between means. Since the smallest average percentage of aborted pollen for any collection was not below 15 and for most collections was 18 or above, and since the between-plot variances for the different collections were homogeneous, transformation of the data was not necessary. Because the majority of the values for microcytes were below 10, the transformation, $\sqrt{X + 0.5}$, was used in analyzing the data for testing the significance of differences between means for number of microcytes among 100 pollen grains. X is the observed number. In calculating the variances the observed values for both characters were used rather than any transformation of them. The following were employed

[1]Contribution from Guayule Research Project, U. S. Dept. of Agriculture, Agricultural Research Administration, Bureau of Plant Industry, Soils, and Agricultural Engineering, Salinas, Calif. Received for publication October 28, 1944.

[2]Principal Geneticist and Assistant Geneticist, respectively. The authors wish to express their appreciation to Dr. A. D. Bergner for the chromosome-number determinations.

[3]Figures in the parenthesis refer to "Literature Cited", p. 193.

in determining the significance of differences: For means, the "t test"; for variances, Bartlett's test for homogeneity of variances; and for frequency distributions, Chi-square. Differences giving odds as great as or greater than 19:1 against the deviations noted being attributable to chance were considered as statistically significant. Any differences discussed in the remainder of this article have been tested by one of the methods listed above, and unless otherwise stated have been found statistically significant.

More detailed information concerning the variances to be discussed later is essential to a logical interpretation of them. In analyzing the data the normal and aberrant classification (for a description of these two classes see Powers and Rollins (5)) was taken into account. The variances listed in Table 1 are the within-plot variances for the normal plants and are for a single determination. By so calculating the variances the majority of the variability due to differences between collections was removed. Some of the more obvious factors contributing to differences between collections are method of reproduction, chromosome number, type of selection practiced, location, and type of plant (normal or aberrant). The degrees of freedom listed in Table 1 are for the variances given in that same table.

EXPERIMENTAL DATA

The experimental data for the means and within-plot variances for percentage of aborted pollen grains and number of microcytes among 100 pollen grains are given in Table 1. The data in this table are further classified according to (a) method of reproduction (amphimixis or apomixis); (b) location from which the seed was collected; (c) type of plant (better type guayule plants and intermediate type guayule plants);[4] (d) commercial variety; (e) collection; (f) chromosome number; and (g) the type of selection practiced, if any, at the time the seed was collected. The experimental data for percentage of aborted pollen grains and number of microcytes will be analyzed on the basis of the associations revealed by this classification. In considering mean percentage of aborted pollen and the variances for this character, the first five classes will be discussed together and the last two separately.

ABORTED POLLEN

METHOD OF REPRODUCTION, LOCATION, TYPE OF PLANT, VARIETY, AND COLLECTION

The mean percentages of aborted pollen grains are given in the fifth column of Table 1. The range in expression of this character for the plants reproducing by means of amphimixis is from 15 to 29% and for the better type guayule plants (those showing fewer characteristics of mariola as compared with the intermediate type plants) reproducing by means of facultative apomixis is from 16 to [illegible]%. Thus, it is evident that the important differences are not between methods of reproduction but are within these two broad classes. In addition, it can be seen from the data of Table 1 that the variances are considerably larger for those collections reproducing by means of amphimixis. Since the variances are the "within-plot" variances, this shows, as might be expected, that the variability between plants is greater for the collections reproducing amphimictically than it is

[4]See Lloyd (4) for a description of these two types of *P. argentatum*. It should be noted that Lloyd uses *P. Lloydii* Bartlett to designate the intermediate type plants.

TABLE 1.—*The means and within-plot variances for percentage of aborted pollen grains and for number of microcytes among 100 pollen grains.*

Collection and accession number	Location or variety	Selection practiced	Degrees of freedom	Aborted pollen grains		Mycrocytes among 100 pollen grains	
				Mean, %	Variance	Mean, No.	Variance
			Amphimixis				
			36+ Chromosomes, Mexico				
4255	Durango	None	85	22	384.764	0.1	0.107
4254	Durango	Mass	83	15	117.448	0.2	0.362
4253	Durango	Ind. Pl.*	83	29	379.254	0.1	0.574
4250	Durango	None	80	18	240.193	0.1	0.110
4251	Durango	None	87	20	289.661	0.1	0.124
			Facultative Apomixis				
			54± Chromosomes, Mexico				
4257	Durango	Ind. Pl.*	82	34	62.585	5.0	12.557
4263	Durango	Mass	86	23	96.581	4.7	7.401
4265	Durango	Mass	80	23	72.406	4.5	13.389
			72± Chromosomes, Mexico				
4259	Nuevo Leon	None	159	19	194.532	3.2	14.590
			Southern Trans-Pecos Area of Texas				
4267	Shafter	None	71	21	93.124	1.5	3.661
4268	Shafter	Mass	74	24	174.204	2.1	5.772
42419	Plata	None	69	19	132.069	2.3	2.296
42420	Plata	Mass	68	19	37.124	2.3	2.457
42217	Fresno Canyon	None	74	21	163.835	1.8	2.816
42218	Fresno Canyon	Mass	76	21	71.620	2.1	5.468
4278	02 ranch	None	68	22	168.509	3.2	8.200
4279	02 ranch	Mass	70	22	116.766	2.1	2.631
42102	02 ranch	Ind. Pl.*	70	19	110.981	2.3	6.040
42173	Santiago Peak	None	70	16	51.429	2.3	5.686
42174	Santiago Peak	Mass	72	19	89.038	2.7	8.186
42383	Wyatt ranch	None	72	18	76.911	2.3	3.420
42384	Wyatt ranch	Mass	73	19	69.706	2.2	2.166
42385	Wyatt ranch	Mass	77	18	71.822	2.3	3.236
42386	Wyatt ranch	Ind. Pl.*	74	22	91.134	1.9	2.310
42387	Wyatt ranch	Ind. Pl.*	78	19	80.954	1.5	1.892
			Northern Trans-Pecos Area of Texas				
42353	Tesnus	None	83	21	157.872	1.7	2.916
42354	Tesnus	Mass	76	22	157.584	2.0	2.524
42355	Tesnus	Mass	77	21	102.328	2.0	4.009
42356	Tesnus	Ind. Pl.*	172	16	81.195	1.4	1.867
42357	Tesnus	Ind. Pl.*	163	18	72.886	2.0	4.133
42239	Neal ranch	None	73	22	111.121	2.7	4.504
42240	Neal ranch	Mass	77	20	69.318	2.7	4.623
42274	Balmorhea	None	81	21	97.571	2.6	5.876
42275	Balmorhea	Mass	168	20	72.369	3.1	6.912
42292	Balmorhea	None	79	22	102.657	2.6	4.526
42293	Balmorhea	Mass	86	22	83.321	3.3	9.813
42255	Fort Stockton	None	82	23	97.435	3.0	14.403
42261	Fort Stockton	None	32	20	77.609	3.0	3.686
42306	Fort Stockton	None	71	23	70.595	2.1	3.376

*Individual plant selection.

TABLE 1.—*Concluded.*

Collection and accession number	Location or variety	Selection practiced	Degrees of freedom	Aborted pollen grains		Mycrocytes among 100 pollen grains	
				Mean, %	Variance	Mean, No.	Variance
			Intermediate Type Plants				
42261	Fort Stockton	None	45	34	140.109	7.2	19.198
4273	Shafter	None	81	31	171.540	15.5	51.299
42331	Sanderson	None	73	41	172.077	16.1	37.195
			Commercial Varieties				
42441	593		67	27	113.180	1.8	5.785
42438	444		56	28	102.544	1.4	1.416
42440	130		68	30	156.234	1.8	5.750
42474	406		57	30	134.950	1.7	2.559

for those reproducing apomitically. That these amphimictic collections are at least largely cross-fertilized has been shown by Powers Rollins (5). With this information it becomes apparent that both heterozygosity and heterogeneity are predominant factors in causing the variability noted in the amphimictic collections.

Whether the same is true of the variability for those collections reproducing by means of facultative apomixis remains to be determined. The means for percentage of aborted pollen grains provide some evidence. For all locations the range in mean percentage of aborted pollen grains of the different facultative-apomictic collections is from 16 to 41%. Within any one location possessing predominantly 72±-chromosome plants the greatest range occurs for Tesnus, being from 16 to 22%. The highest mean percentage of aborted pollen grains occurs among the intermediate type plants, the next highest among the 54±-chromosome collection, and the third highest among the commercial varieties. The differences between the collections of the 54±-chromosome group and those of the intermediate type plants are statistically significant, whereas the differences between the commercial varieties are not. These data are conclusive in showing that both the locations and the collections within locations in some cases form heterogeneous groups and, therefore, that heterogeneity is one of the major contributors to variability in this facultative-apomictic material.

The variances of these collections furnish additional information concerning heterogeneity and critical evidence as to whether heterozygosity plays any part in determining variability. It can be seen from the data of Table 1 that the range of variances for the facultative-apomictic collections from Mexico and the range of those from the Trans-Pecos area of Texas are too similar to justify the conclusion that the variability of collections from one are different from the variability of the collections from the other. However, the following is shown by the data. The variance of the collection from Nuevo

Leon is higher than the variances of the facultative-apomictic collections from Durango. The variances for the intermediate type plants, the commercial varieties, the 02 ranch, and for the first two collections of Tesnus are higher than the variances for Santiago Peak, Wyatt ranch, Neal ranch, Balmorhea, and Fort Stockton. Differences exist between variances of collections within the following locations: Shafter, Plata, Fresno Canyon, and Tesnus.

The following conclusions can be drawn from these facts: Differences between locations for these within-plot variances show that guayule *P. argentatum*, is a heterogeneous species in respect to percentage of aborted pollen grains. Differences between collections as to "within-plot" variances prove that not only does heterogeneity exist in respect to collections within locations but also in respect to plants of the same collection. It remains to determine whether individual plants are heterozygous. The evidence is indirect but conclusive. Powers and Rollins (5) have shown that a certain proportion of the progeny from these apomictic collections arises as a result of normal sexuality (reduction followed by fertilization) and that cross-fertilization is common in guayule. Since, as has been shown, some of the collections are heterogeneous, then it follows that cross-fertilization would cause at least some of the sexually reproduced plants to be heterozygous. Consequently, some of the variability of these facultative-apomictic collections is due to heterozygosity. However, it seems that in most of them plant heterozygosity would account for only a minor proportion of the immediate variability. Nevertheless, this source of variability undoubtedly is of considerable importance from the standpoint of evolution and hence plant breeding also.

CHROMOSOME NUMBER

Likewise, information concerning the association between differences in percentage of aborted pollen grains and chromosome number can be obtained from the data of Table 1. The chromosome numbers 36+, 54±, and 72± occur for different collections of guayule (2, 7).

As regards the 36+- and 72±-chromosome groups, the ranges in mean percentage of aborted pollen grains overlap to such an extent (Table 1) as to make questionable the reliability of any conclusion that may be drawn from a comparison of them. However, such is not true of the variances. In general, the collections of the 36+-chromosome group possess variances exceeding those of the collections possessing 72± chromosomes. Since all collections of the 36+-chromosome group reproduce primarily by means of amphimixis and those of the 72±-chromosome group by means of facultative-apomixis, it seems that the differences noted in size of variances are directly attributable to the method of reproduction rather than chromosome number.

The mean percentage of aborted pollen for the 54±-chromosome group is somewhat greater than the mean percentage of aborted pollen for either of the other two groups. Hence, the question arises as to whether this can be attributed solely to differences in chromosome number. With respect to the 36+- and the 72±-chromosome

groups the 54± group represents the 3n condition (7) and therefore might be expected to have a higher percentage of aborted pollen due to meiotic irregularity. Such being the case it is difficult to explain why collections Nos. 4263 and 4265 have a mean percentage of aborted pollen only slightly greater than the 36+-chromosome group and the 72±-chromosome collections of the better guayule type from Mexico and the Trans-Pecos Area of Texas; whereas, collection No. 4257 has a considerably greater percentage, 34, of aborted pollen grains. It could be that a few exceptional individuals were responsible for the higher percentage of aborted pollen for collection No. 4257. The small variance of this collection indicates that such was not the case.

To provide further information the plant frequency distributions for percentage of aborted pollen grains of representative 36+-, 72±-, and 54±-chromosome collections are given in Table 2. Chi-square tests applied to the data given in this table show that there are four distinct frequency distributions among the five collections listed only those of No. 4265 and No. 4263 being nondistinguishable from each other. Here it should be noted that the extreme deviate (85% aborted pollen) of No. 4263 is an interspecific hybrid involving *P. incanum* (mariola). If chromosome number was the sole cause of variability, only three distinct frequency distributions would be expected. It is evident from an examination of these distributions that the differences between the frequency distribution of collection No. 4257 and those of the other two 54±-chromosome collections cannot be attributed to a few extreme individuals of No. 4257.

TABLE 2.—*Plant frequency distribution for percentage of aborted pollen grains of 36+, 72±, and 54± chromosome collections.*

Collection No.	Chromosome number	Percentage of aborted pollen grains																					Total
		0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	
4255	36+	0	21	15	15	12	8	4	1	2	4	3	2	1	2	1	1	–	–	–	1	–	93
42102	72±	0	7	13	31	10	10	5	2	1	1	–	2	1	1	–	–	–	–	–	–	–	84
4265	54±	0	2	10	11	21	16	14	9	4	1	–	–	–	–	–	–	–	–	–	–	–	88
4263	54±	0	1	8	21	22	20	12	7	0	2	–	–	–	–	–	–	–	1	–	–	–	94
4257	54±	0	0	0	0	12	15	24	16	9	5	9	3	–	–	–	–	–	–	–	–	–	93

Before proceeding further with the analysis, the histories of collection Nos. 4255 and 4257 and the possible relationship between the two should be given, because together they furnish a very plausible explanation as to why the mean percentage of aborted pollen grains is high (comparatively speaking) for No. 4257. These collections are from the same natural population which was growing in a valley at the foot of limestone hills a few miles northeast of Santa Librada. Collection No. 4255 was grown from a random nonselected seed sample, whereas collection No. 4257 was grown from seed collected from an individual plant. Collection No. 4258 (not included in this experiment) is the progeny from an individual plant selection

of this same natural population and it has 72± chromosomes. Hence, this natural population is composed of 36+-, 54±-, and 72±-chromosome plants. Both No. 4257 and No. 4258 reproduce by means of facultative apomixis. It may be that No. 4257 represents a natural hybrid between a 36+-chromosome plant and a 72±-chromosome plant from this area, a 36+-chromosome plant being the female parent. The chromosome number was counted for only nine plants of collection No. 4255; but all of these nine had 36+ chromosomes. That other plants of this collection may have 54± and 72± chromosomes is probable. Hence, it seems that No, 4257 may be a natural hybrid as suggested above. If such were the case, the high percentage of aborted pollen grains as compared with Nos. 4265 and 4263 is due to the bringing together of certain genetic complexes by intraspecific hybridization rather than to differences in chromosome number.

Further information concerning the relative importance of chromosome number in determining the percentage of aborted pollen grains can be obtained by studying the collections of the 72±-chromosome group. The means of the intermediate type plants from Fort Stockton and Shafter are considerably higher than the means of the better type guayule plants from these same locations. The intermediate type plants from Sanderson have the highest mean percentage of aborted pollen of any location. Collection No. 42261 is composed of both types of plants and therefore provides an opportunity for comparing types from one natural population. The better guayule type plants averaged 20% of aborted pollen grains, whereas the intermediate type plants averaged 34%. The greater percentage of aborted pollen grains of these intermediate type plants might be attributed to the introgression of mariola, *P. incanum*, chromosomes or part of chromosomes. Rollins (6) has shown that mariola has played some part in the origin of these intermediate type plants. Here again hybridization played an important part in determining the percentage of aborted pollen grains by allowing the combining of certain gene complexes. In this case interspecific hybridization and further crossing of the progeny with plants of *P. argentatum* undoubtedly took place. This further hybridization could account also for the differences noted between collections of intermediate type plants. That the commercial varieties are uniformly higher in mean percentage of aborted pollen grains than the better type guayule plants of the 72±-chromosome group furnishes additional evidence that number of chromosomes is not the predominating factor in determining the percentage of aborted pollen grains produced by a plant or collection.

TYPE OF SELECTION PRACTICED

In making the selections from natural populations the percentage of aborted pollen grains was not determined and hence selection taking this character into consideration could not be practiced. The characters considered in making the individual plant and mass selections were size of plant, vigor of plant, freedom from dead or diseased appearing branches, and proportion of bark to wood. In case of the better guayule type plants characteristics of mariola were avoided.

The data will be examined to determine what effect, if any, selecting on the basis of the characters listed above had on the mean percentage of aborted pollen and the variability (variances) of this character. Collection No. 4253, which is the progeny from an individual plant, is higher in mean percentage of aborted pollen and is more variable than the progenies of the nonselected samples, collections No. 4250 and 4251, and the mass selection No. 4254. The reverse is true for the same comparisons involving the individual plant selections, the random sample (nonselected) and mass selections from Tesnus. The progeny of the mass selection from Shafter was more variable than the progeny of the nonselected collection from the same location; whereas the reverse was true of the same comparisons for the seed collected from Plata and Fresno Canyon. The inconsistency of the results shows that selection as practiced had no general effect on the means or variances for percentage of aborted pollen grains. However, the differences noted between the progenies of selected or nonselected collections prove that the material is highly heterogeneous and that at least some of the plants are highly heterozygous for the gene pairs differentiating percentage of aborted pollen grains.

NUMBER OF MICROCYTES

On the basis of number of microcytes the classifications in Table 1 rank in the following ascending order: Amphimixis and 36+ chromosomes, commercial varieties, southern Trans-Pecos Area of Texas, northern Trans-Pecos Area of Texas, 54±-chromosome group, and intermediate type plants. The most logical interpretation of these associations is that amphimixis and the low chromosome number of the 36+-chromosome group are the most dominant factors in determining whether a given collection shall have a low percentage of microcytes. The somewhat higher mean percentage of microcytes of the facultative-apomictic 54±-chromosome collections as compared with the 72±-chromosome collections may be due to the fact that they represent the 3n condition as compared with the 36+-and 72±-chromosome groups. Stebbins and Kodani (7) believe that the basic number of chromosomes (lx) is 9 for *Parthenium argentatum*. The high percentage of microcytes for the intermediate type plants probably is due to the introgression of mariola (*P. incanum*) chromosomes or parts of chromosomes. The range within the intermediate type plants is from 7.2 to 16.1%, showing that these collections form a heterogeneous group and that the gene complexes within this group are important factors in determining the percentage of microcytes formed by a plant or collection.

With the exception of the intermediate type plants the differences between collections within locations and between locations within the foregoing classes are so minor as not to merit further consideration. Also, there are no significant differences that can be attributed to any general effect of the types of selection practiced.

The large variances of the 54±-chromosome collections, of those possessing intermediate type plants, and of collection Nos. 4259 and 42255 show that the plants of these collections form a hetero-

geneous group. This fact would lead one to suspect that individual plant selection within collections Nos. 4259 and 42255 might lead to the production of 72±-chromosome strains having a lower mean number of microcytes than any 72±-chromosome strain now available.

The frequency distributions for number of microcytes for the 54±-chromosome collections and for representative collections of the 36+- and 72±-chromosome groups are given in Table 3. The greatest variability is encountered in the 54±-chromosome group. The frequency distributions for Nos. 4263 and 4257 are not significantly different but that for No. 4265 as determined by the X^2 test is quite different from the other two. More individuals occur in the lower classes of this collection. This shows that selection within this collection would almost certainly result in strains with a decidedly lower number of microcytes.

TABLE 3.—*Plant frequency distribution for number of microcytes of 36+, 72±, and 54± chromosome collections.*

Collection No.	Chromosome number	Number of microcytes																								
		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	Total
4255	36+	91	1	0	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	93
42102	72±	18	19	18	14	6	3	3	1	—	—	1	—	—	—	—	1	—	—	—	—	—	—	—	—	84
4265	54±	13	9	16	11	8	12	2	5	0	2	3	1	0	2	1	2	1	—	—	—	—	—	—	—	88
4263	54±	3	4	13	15	17	14	6	6	7	2	5	1	—	—	—	1	—	—	—	—	—	—	—	—	94
4257	54±	5	2	15	13	16	11	7	5	5	5	3	3	1	—	—	—	1	—	—	—	—	—	—	1	93

A joint comparison of the frequency distributions of the 54±-chromosome collections given in Tables 2 and 3 is informative. Chi square tests show that the frequency distributions of collection Nos. 4265 and 4263 given in Table 2 are nondistinguishable, but that the frequency distribution of No. 4257 is different from the other two; whereas the frequency distributions of collection Nos. 4263 and 4257 are nondistinguishable in Table 3 but that of No. 4265 is different from the other two. This shows that Nos. 4265 and 4263 have similar genetic complexes as regards the percentage of aborted pollen grains but different complexes as regards frequency of microcytes and that the reverse is true as regards the same comparison for Nos. 4263 and 4257. This proves that the 54±-chromosome collections form a heterogeneous group as regards both percentage of aborted pollen grains and number of microcytes.

SUMMARY AND CONCLUSION

Guayule, *P. argentatum*, possesses considerable genetic variability as to percentage of aborted pollen grains and frequency of microcytes. Both heterogeneity and heterozygosity were found to be important factors in determining variability. For mean percentage of aborted pollen grains the genetic variability is great within the classes based on the following: Method of reproduction, chromosome number,

location, type of plant, region of Trans-Pecos Area of Texas, and collection. The same was not true for mean number of microcytes in respect to amphimixis, the 36+- and 54±-chromosome groups, location, and region of Trans-Pecos Area of Texas; but was true as regards facultative apomixis, the 72±-chromosome group, type of plant, and location. This shows that selection as a method of breeding would be very effective in respect to both characters, and further, it shows within which classes the most rapid progress can be made.

The fact that natural hybridization played such an important part in bringing about and maintaining variability proves that much can be accomplished by the hybridization method of breeding.

LITERATURE CITED

1. BELLING, JOHN, and BLAKESLEE, ALBERT F. The assortment of chromosomes in triploid daturas. Amer. Nat., 54:339-346. 1922.
2. BERGNER, A. D. Guayule plants with low chromosome numbers. Science, 99:224-225. 1944.
3. LEE, ARTHUR BOLLES. The Microtomist's Vade-Mecum. Philadelphia: P. Blakiston's Son and Co. Inc. 1937.
4. LLOYD, F. E. Guayule (*Parthenium argentatum* Gray): A rubber plant of the Chihuahuan desert. Carnegie Inst. Pub., No. 139. 1911.
5. POWERS, LEROY, and ROLLINS, REED C. Reproduction and pollination studies on guayule, *Parthenium argentatum* Gray and *P. incanum* H.B.K. Jour. Amer. Soc. Agron., 37:96-112. 1945.
6. ROLLINS, REED C. Evidence for natural hybridity between guayule (*Parthenium argentatum*) and mariola (*Parethnium incanum*). Amer. Jour. Bot., 31:93-99. 1944.
7. STEBBINS, G. LEDYARD, and KODANI, MASUO. Chromosomal variation in guayule and mariola. Jour. Heredity, 35:163-172. 1944.

THE EFFECT OF MOISTURE STRESS ON NURSERY-GROWN GUAYULE WITH RESPECT TO THE AMOUNT AND TYPE OF GROWTH AND GROWTH RESPONSE ON TRANSPLANTING[1]

Omer J. Kelley, Albert S. Hunter, and Clinton H. Hobbs[2]

IN THE production of any crop it is of considerable interest to know the effect of moisture stress on the amount and type of growth produced. This is particularly true for plants such as guayule, *Parthenium argentatum* Gray, which are grown in irrigated nurseries for later transplanting to field sites. In the case of such plants, the moisture stresses under which they are grown not only affect the amount and type of growth of the nursery stock but may also affect the survival and the time required for resumption of growth after the plants are set in the field.

There is some disagreement in the literature as to the importance, in relation to plant growth, of soil moisture held at tensions or stresses below the wilting coefficient (1, 3, 4, 6, 8, 9, 12, 13, 14, 15, 24, 26, 32, 33).[3] Several investigators have reported that continuously maintained low moisture stresses gave growth increases for various crops; others have held to the view that plants grow equally well over the range of moisture stresses between the field capacity and the wilting point.

Very few references to the growth and survival after transplanting of woody plants grown in the nursery under varying degrees of moisture stress are to be found in the literature. Shirley and Meuli (27) reported that the drought resistance and survival of transplanted conifer seedlings were affected by the moisture conditions under which they had been grown in the nursery, growth under conditions of low soil moisture resulting in increased ability to survive. George (10) stated that nursery stock grown under dry land conditions produced better hardwood nursery stock for tree plantings in the Great Plains area than plants grown with irrigation. The literature is particularly lacking in references to guayule culture. The unpublished data and records of the Intercontinental Rubber Company (16) are the principal sources of information.

It has been the normal practice to grow guayule seedlings in the nursery and, after they reach some arbitrary size, to subject them to a "hardening off" process and transplant them into the field. With this type of culture it is of primary importance to produce nursery stock which will survive transplanting and resume growth quickly.

When investigations on guayule were undertaken by the Emergency Rubber Project, the exact type of plant and treatment needed

[1]Contribution from Special Guayule Research Project, Bureau of Plant Industry, Soils and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture, Salinas, Calif. Received for publication November 4, 1944.

[2]Soils Technologist, Associate Soils Technologist, and Assistant Plant Physiologist, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 214.

for maximum survival and rapid rejuvenation of growth were not known. It was evident, therefore, that there were several soil moisture problems which needed to be studied, among the more important of which were (a) Under what moisture stress range should guayule nursery stock be grown for maximum survival and most rapid resumption of growth upon transplanting? (b) What is the optimum moisture stress range for maximum growth of nursery seedlings? (c) From what part of the soil profile do guayule seedlings obtain their water? (d) What are the effects of various soil moisture stresses on the rubber content and internal structure and composition of guayule nursery seedlings? The answering of these questions was the objective of the experiment here reported.

PLAN OF EXPERIMENT

Guayule nursery seedlings were grown under five different soil moisture stress ranges, each in combination with two superimposed levels of fertility, on the Chualar loam soil of the Alisal Nursery at Salinas, Calif. The moisture treatments were designed to maintain soil moisture stresses in the following ranges:

Treatment I, between the field capacity and a tension of 850 cms. of water at the 6-inch depth.

Treatment II, between the field capacity and a tension of 850 cms. of water at the 12-inch depth.

Treatment III, between the field capacity and the wilting point at the 6-inch depth.

Treatment IV, between the field capacity and the wilting point at the 12-inch depth.

Treatment V, regardless of the moisture stresses developed the plants were to receive no water after they were well established.

The plants were seeded on June 3, 1943. Winter rains and pre-irrigation had wet the soil to a depth of at least 6 feet. Similar moisture treatments were given to all plots until July 13, at which time the plants were considered to be well established and differential moisture treatments were begun. The total amount of irrigation water applied varied from 2.5 acre-inches per acre for treatment V to 25.3 acre-inches per acre for treatment I. The differential moisture treatments were discontinued September 14. After that date moisture applications were uniform and due only to rainfall.

The two fertility levels were (a) natural fertility until midsummer, August 12, followed by an addition of 50 pounds of nitrogen per acre; and (b) 500 pounds of 10–15–5 fertilizer drilled in to a depth of 4 to 6 inches prior to seeding, and an additional 50 pounds of nitrogen per acre applied August 12.

Each moisture treatment was randomly replicated eight times on plots 24 feet long and composed of two contiguous nursery beds, each having seven rows spaced 7 inches apart. One bed received fertility treatment A, the other received fertility treatment B. During the growing season samples of plants were taken periodically for the determination of dry weight and contents of mineral nutrients and rubber. Beginning in September 1943, at intervals during the next 9½ months plants from all moisture treatments were transplanted into the field for studies of the effects of previous moisture treatment upon their resumption of growth and their survival.

RESULTS AND DISCUSSION

SOIL MOISTURE DATA

Changes in the soil moisture content were followed by means of oven-dried samples, Richards tensiometers (22), and Bouyoucos plaster of paris blocks (7). The discussion that follows is concerned principally with data obtained by the first method. A more detailed

discussion of the data obtained with the tensiometers and Bouyoucos blocks, and of the uses and limitations of these instruments in field practice, will be given elsewhere.

The moisture data obtained from oven-dried soil samples for the first four moisture treatments are shown graphically in Fig. 1. The permanent wilting point and the field capacity at the 0 to 12-inch depth were determined by the methods of Veihmeyer (31, 34) to be 6% and 16%, respectively. A moisture-tension curve (23), from 0

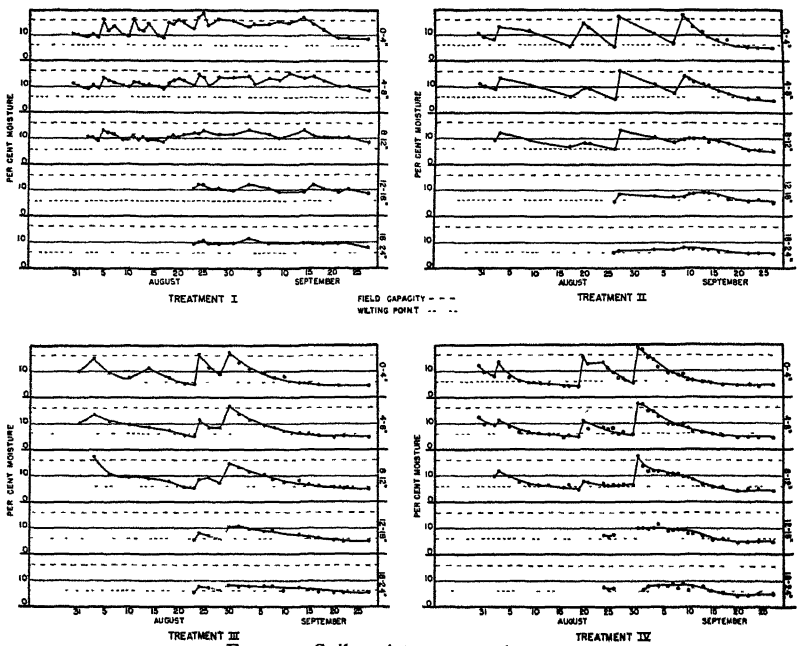

FIG. 1.—Soil moisture record, 1943.

to 1 atmosphere tension, is given for the Chualar loam soil in Fig. 2. It is evident from this curve that only about one-third of the available moisture is held in the range between the field capacity and the 1 atmosphere value, and that in this range for a small change in moisture content there is a large change in tension.

As is shown in Fig. 1, the moisture content of the first foot of the soil receiving treatment I was very high throughout the period of differential treatment, especially in the surface 4 inches. Conversely, the moisture stress was very low, as is shown in Fig. 3, where the moisture tension at the 6-inch depth, as measured by a tensiometer, is plotted against time for one replication of treatment I. The soil at the 12- to 18-inch depth was at a somewhat lower moisture level, but still high when considered in relation to the wilting point of this soil. As is indicated in Fig. 1, there was little change in moisture content in the lower depths when the moisture stress near the surface was very low. The plots of treatment II were kept relatively wet

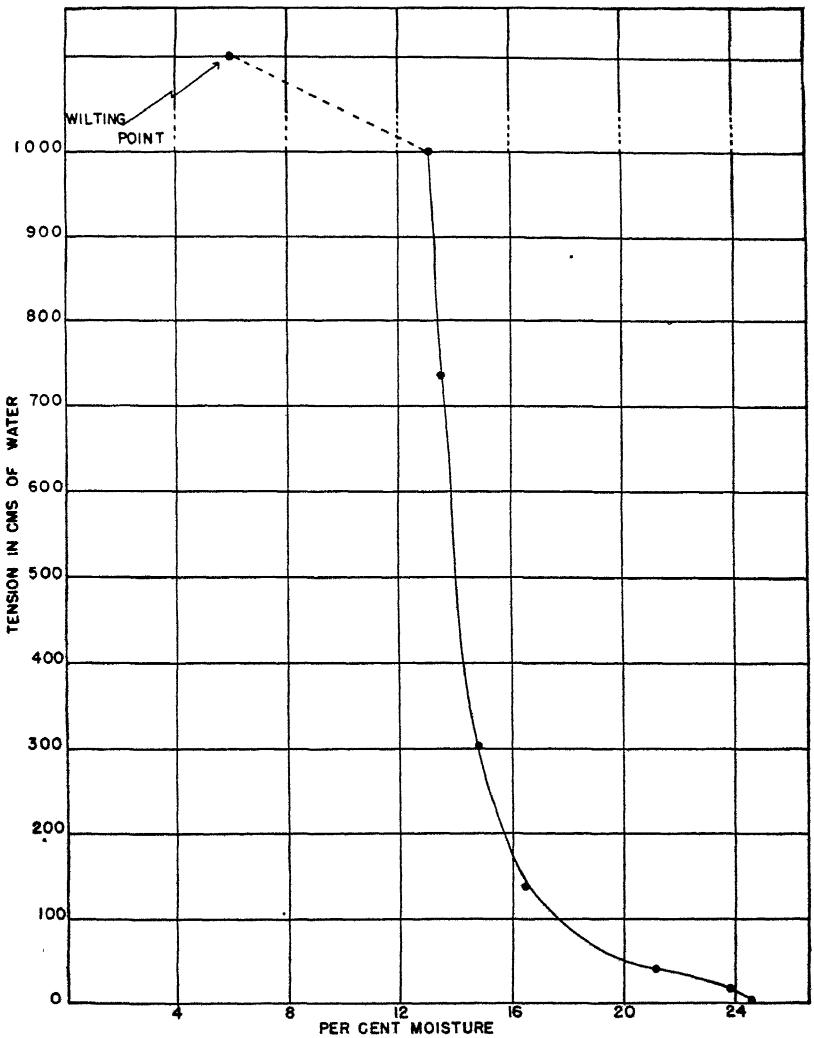

FIG. 2.—Moisture-tension curve for Chualar loam soil at 4- to 6-inch depth.

(low tension) in the top 24 inches, although the moisture level was much lower than in the plots of treatment I. At 12 inches the moisture content fell to the wilting point only twice during the differential treatment and then for only a very short period. The moisture conditions of treatment III, although planned to differ from those of treatment II, actually were similar. It should be pointed out that in neither moisture treatment II or III was the soil moisture maintained exactly within the ranges set up for these treatments.

The soil of plots receiving treatment IV was at a much lower moisture level (higher stress) than that of those receiving treatments I, II,

or III. For a considerable portion of the time the moisture content of these plots was near that of the wilting point, that is to say, the soil moisture was held under a high stress, or tension. Continuous moisture data for treatment V were not obtained. Since the plots of treatment V were not irrigated after July 13, it is certain that their moisture content was considerably less than was the case for treatment IV plots. In mid-September the soil moisture content of these plots was found to be below the wilting point throughout the depth of root penetration. It had probably been in that range since early in August.

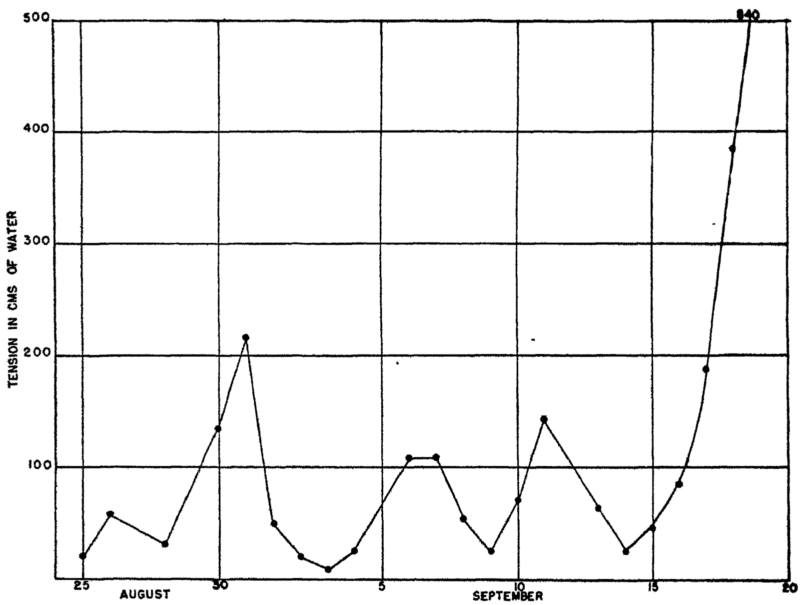

FIG. 3.—Soil moisture tension for treatment I vs. time at 6-inch depth.

The only moisture received by any of the plots after September 14 was due to rainfall. This amounted to 0.36 inch in October, 0.24 inch in November, 2.49 inches in December, and 2.51, 5.89, 1.19, 1.31, and 0.52 inches in January, February, March, April, and May, respectively (30).

AMOUNT AND TYPE OF GROWTH IN THE NURSERY

The differential effects of the several moisture treatments upon the growth of the plants in the nursery were measured by dry weight determinations at five dates during the season: July 10, July 23, August 21, September 28, and October 19. The data are presented in Table 1. The given weights are the means, for tops plus a portion of the main roots (approximately 4 to 7 inches of root, depending upon

the age of the plants[4]) of from one to four samples from each of eight replicates.

TABLE I.—*Dry weight determinations.*

Sampling date	Moisture treatment* I	II	III	IV	V	Size sample, linear inches of row	Number samples per plot	Differences required for significance at P=0.05	P=0.01
July 10..	0.97	1.12	1.01	1.36	—	15	2	0.27	0.37
July 23..	5.64	5.71	5.43	6.30	—	15	4	—†	—†
Aug. 21..	29.8	30.5	28.3	25.7	—	15	4	2.9	3.9
Sept. 28.	264.6	232.4	240.0	218.4	103.8	60	1	23.6	32.0
Oct. 19..	272.6	253.5	236.3	230.9	111.9	60	1	22.6	32.5

*Dry weight in grams per sample, mean of eight replicate plots.
†No significant difference by the F test.

At the first three sampling dates the sample obtained comprised a 3-inch section across the five inside rows in the seven-row nursery bed, or 15 linear inches of row; at the two later samplings a 12-inch section, or 60 linear inches, was taken. The two differentially fertilized halves of each moisture plot were sampled separately at the second and third sampling dates, but statistical treatment indicated no significant differences and consequently only means for the moisture treatments are presented. (Simultaneously a comprehensive fertility experiment was being conducted adjacent to this experiment, and it was found that this soil contains ample amounts of phosphorus and potassium for maximum growth of guayule nursery seedlings.) At the first, fourth, and fifth sampling dates samples were taken only from the fertility treatment B part of the plots. Samples were not obtained at the first three sampling dates from the plots of treatment V.

The July 10 sampling was made just prior to initiation of the differential moisture treatments. The treatment to that date had been uniform, hence a significant difference was unexpected. There was, however, a difference in favor of the plots later to receive treatment IV. The F test indicated that the differences due to treatment were not statistically significant on July 23. By August 21 the plants of treatment I and II had produced significantly greater dry weight than those of treatment IV. By September 18 there were highly significant differences due to irrigation treatment. Treatment I had produced significantly more dry weight and treatment V had produced significantly less than any other treatment. This was also true at the sampling on October 19.

A general view of a portion of the experimental plots is given in Fig. 4, together with a comparison of the tops of representative plants from each treatment. It is obvious that the type of top growth produced by the several treatments differed markedly. Those plants

[4]As the plants aged it was necessary to go deeper in order to obtain the major portion of the roots.

grown under continuous low moisture stresses produced a large vegetative growth and flowered profusely, while the opposite was true for plants grown under high moisture stresses. The plants of treatment V made only a fraction as much vegetative growth as those of treatment I, and only a few of them flowered at all during the summer. There were also striking differences in the color and other physical characteristics of the plants. Those grown with the larger amounts of water were very succulent, brittle, and their leaves were light

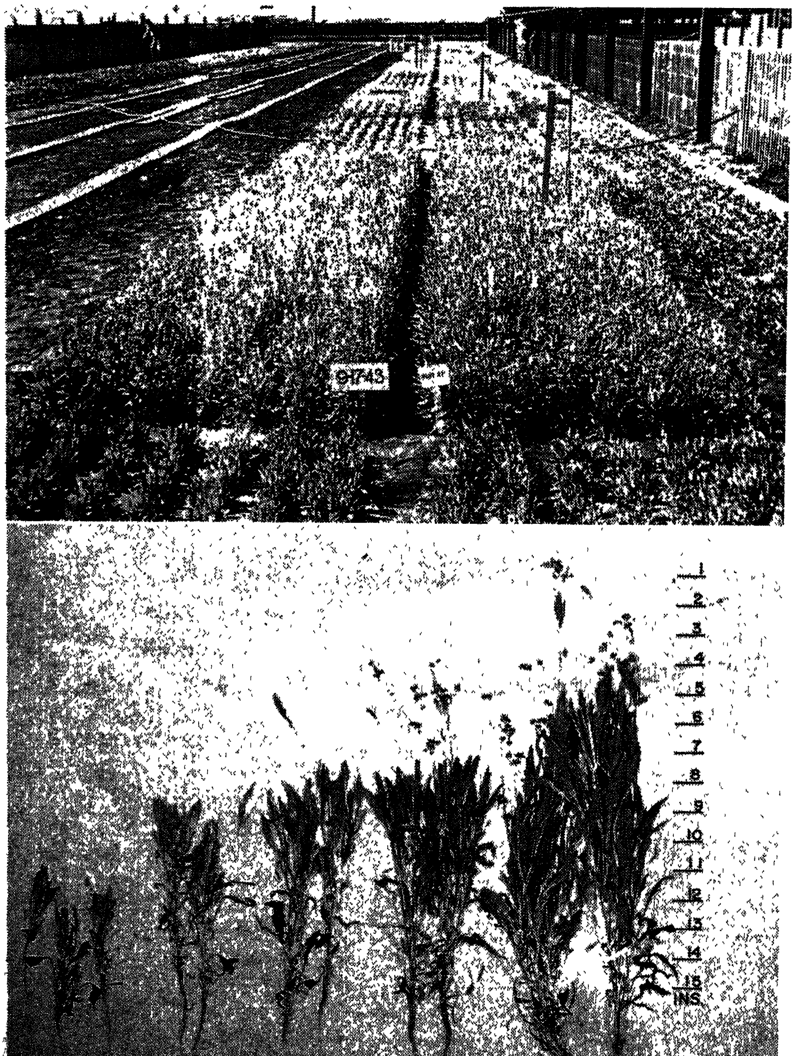

FIG. 4.—General view of experimental plots and a comparison of the tops of representative plants from each moisture treatment.

green in color; in contrast, those grown under the higher moisture stresses were shriveled, tough, and in leaf color a bluish-gray. This latter color of the leaves is thought to be indicative of plants that are in a good condition for transplanting.

Since the plants produced by the several moisture treatments differed so greatly in top growth, it was thought that there might be corresponding differences in root development. In mid-September Dr. C. H. Muller[5] made some studies of the roots of plants grown under treatments I, II, and V. Treatments I and V represented the extremes in moisture stresses and in top growth and might logically be expected to display the maximum variation in the development of the roots. Drawings of the roots produced by the three treatments are shown in Fig. 5.[6] There was little difference in the depth of root penetration. Possibly the differences would have been greater had there been present a well-aerated subsoil of texture similar to that of the surface soil. In this case there was in the subsoil at around 42 to 48 inches a heavy layer in which both iron and manganese were present to some extent in a reduced state early in the season. The presence of this heavy layer may have been responsible for a considerable reduction in root growth. The plants of treatment V had fewer lateral roots near the soil surface than those of treatments I and II. This might be expected, since the soil of the treatment V plots had been under very high moisture stress for most of the summer. Moisture determinations at the time of the root studies showed that the soil of the treatment V plot was at or below the wilting point for the entire depth of root penetration.

The root-top ratio of nursery stock has sometimes been considered in relation to its transplantability (10). It is possible that in this case differences in this ratio existed and these may have been correlated

FIG. 5.—Comparison of root systems of guayule plants receiving various moisture treatments. (Drawings by courtesy of Dr. C. H. Muller.)

[5]Associate Botanist, Special Guayule Research Project, Salinas, Calif.
[6]Thanks are extended to Dr. Muller for permission to reproduce these drawings.

with the growth and survival of the plants after transplanting. It is evident from a study of the drawings of the root systems and a consideration of the depth of root penetration that any such ratio could be only relative and would have to be based upon an entirely arbitrary portion of the root system, due to the impracticality of completely recovering the roots from the soil. For this reason, no attempt was made to determine the root-top ratio of any of the plants in this experiment.

Measurements were made, however, of the crown-diameter and the height of the aerial portion of the plants. Representative plants of each treatment are shown in Fig. 4. Their heights varied from less than 4 inches for those of treatment V to more than 12 inches for those of treatment I. Data on the total number of plants per square foot, the number of plants of crown-diameter less than 5/32 inch, and the number calipering 5/32 inch and above (except for treatment V, for which the criterion was 4/32 inch) at the date of the second transplanting on October 19 are summarized in Table 2.

TABLE 2.—*Number of plants per square foot sampled October 19, 1943.*

Irrigation treatment	Caliper at the crown	Mean number of plants per sq. ft.*
I	Less than 5/32 inch	13
	5/32 inch and above	23
	Total	36
II	Less than 5/32 inch	20
	5/32 inch and above	24
	Total	44
III	Less than 5/32 inch	16
	5/32 inch and above	23
	Total	39
IV	Less than 5/32 inch	23
	5/32 inch and above	24
	Total	47
V	Less than 4/32 inch†	21
	4/32 inch and above	26
	Total	47

*Mean of eight replications. No significant differences by the F test in total number of plants per square foot.

†For treatment V a criterion of 4/32 inch was employed in order to obtain a number of "transplantable" plants per unit area comparable with the other treatments.

A crown-diameter of 5/32 inch was the criterion of minimum size for "transplantable" stock in the 1943–44 guayule field planting program, hence this value was chosen as the basis for size classification. In some previous years a criterion of 3/32 inch has been used. For treatment V a criterion of 4/32 inch was employed in order to obtain

a number of "transplantable" plants per unit area comparable with the other treatments. A large percentage of the plants of treatment V fell between 4/32 and 5/32 inch. On the basis of the criteria used, there were no significant differences in either the total number of plants per square foot or the number of plants of "transplantable size". Not only did treatment V produce as many "transplantable" plants per unit area as the other treatments, but, as will be shown later, the transplanting responses of the plants from this treatment were far superior to any others.

Except for those removed in sampling, the plants grown in this experiment were left in the nursery through the summer of 1944 without any further moisture applications other than natural rainfall after September 1943. Early in the 1944 growing season it was noted in the nursery that the plants of treatment V sent forth new shoots several weeks earlier than the plants of any other treatment and that their growth was much more vigorous. On July 7 all plots were sampled. The tops of five representative plants from each plot were divided into two portions, one portion (new growth) being the new stem and leaf growth made entirely in 1944, the other portion (old growth) being the stems and leaves laid down in 1943 but including also any accrual due to diametral enlargement and thickening of these parts by reason of 1944 growth. The dry weight was determined for each of these two classes of tissue. The means of eight replicates of five plants each are presented in Table 3. The increment of plant growth during any given period is to a large degree influenced by the initial size of the plant. It is obvious, therefore, that in comparing the 1944 growth of the plants of the various treatments, account must be taken of their size at the beginning of the 1944 season. The ratio of the purely 1944 growth to the 1943 growth, including the accrual due to 1944 enlargement and thickening, is given in Table 3. Relatively, the treatment V plants produced nearly 3 times as much growth during the spring of 1944 as the plants of any other treatment. On the same basis, the plants of treatment I produced significantly less new growth than those of any other treatments. While there were no significant differences in the ratios for the plants receiving treatments II, III, and IV, they showed a general trend paralleling the moisture stresses under which they were grown during 1943. These data on the 1944 spring growth of the plants left in the nursery are in good agreement with the data on the after-

TABLE 3.—*Dry weight of the new and old growth of the top portion of guayule plants sampled July 7.*

Moisture treatment	Dry weight in grams		Ratio of new growth to old growth
	New growth	Old growth	
I	1.85	4.19	0.43
II	2.12	3.77	0.56
III	2.82	4.67	0.58
IV	1.64	2.78	0.59
V	2.83	1.84	1.53

transplanting growth responses of plants from the various treatments discussed later in this paper.

RUBBER AND RESIN CONTENT

The effects of differential moisture stresses on the rubber and resin content of guayule nursery seedlings are of much interest. The interest lies more in the fundamental than in the practical aspects of the physiological behavior of the plant in response to moisture stress, since guayule is seldom grown for rubber in the nursery. It seems quite possible, however, that information obtained from a study of nursery plants would, in part at least, be applicable to field plants grown for a longer time for rubber.

When the plots were sampled on September 28, 1943, for dry weight determinations, the plants of a portion of each sample were divided at the crown into tops and roots. The eight replicates of each treatment were composited, for each portion, for analyses for the content of rubber and resin.[7] The analytical data are presented in Table 4. Since the eight replicates were composited, an analysis of variance could not be made on these data. There were differences between treatments, however, which warrant consideration. The rubber content of the tops and roots of the plants of treatment V were 1.15 and 2.21%, respectively. In contrast, the corresponding values for treatment I were 0.14 and 0.10%. The maximum values for the other treatments were 0.19% rubber in the tops and 0.39% in the roots. Thus, the concentration of rubber in the tops of the treatment V plants was 7 to 8 times as great as in the plants of the other treatments, and in the roots 5½ to 20 times as great. The percentages of rubber in the plants of the first four treatments were not greatly different, but the data show a trend which indicates that even moderate differences in the moisture stresses under which they are grown are reflected in variations in the rubber content of guayule plants at

TABLE 4.—*Rubber and resin analyses.*

Moisture treatment	Plants sampled Sept. 28, 1943*				Plants sampled Feb. 9, 1944†	
	Rubber		Resin			
	Tops, %	Roots, %	Tops, %	Roots, %	Rubber, %‡	Pounds rubber per acre§
I........	0.14	0.10	3.08	1.15	2.5	360
II........	0.17	0.32	3.10	1.93	3.2	354
III.......	0.19	0.37	3.60	2.23	2.9	310
IV.......	0.17	0.39	3.90	1.95	3.7	333
V........	1.15	2.21	4.45	3.88	8.0	348

*Analyses made on composites of all replications.
†Mean of eight replications.
‡Differences required for significance: 0.7% at P =0.05; 1.0% at P = 0.01.
§Based on dry weights per 60 linear inches of row.

[7]All rubber and resin analyses were made by the Rubber Laboratory of this Project, Raiford L. Holmes, Rubber Technologist, in charge.

an early age. The resin content of the tops varied from 3.08% for treatment I to 4.45% for treatment V. For the roots the corresponding values were 1.15 and 3.38%, respectively. Thus, the concentration of resin was 1¼ to 2½ times as high in the tops as in the roots, and in both tops and roots the higher resin concentrations were correlated with increased soil moisture stress.

On February 9, 1944, the plants of the five differential moisture treatments were sampled for determination of rubber content and dry weight yield per acre. After defoliation of the plants, dry weight and rubber determinations were made on the individual samples from eight replicates of each treatment. The mean values for percentage rubber and pounds of rubber per acre are given in Table 4. These data show clearly the effects of differential moisture stresses upon the concentration of rubber in the guayule plant. The rubber content of the 8-month-old plants varied from 8.0% for treatment V to 2.5% for treatment I. The value for treatment V is significantly greater than that for any other treatment. The value for treatment I was significantly lower than that for any other treatment except treatment III. The percentage of rubber was significantly greater for treatment IV than for treatment III. There was no significant difference between treatments II and III.

There were no significant differences by the F test in the pounds of rubber per acre produced by the different moisture treatments. The amount of rubber produced per acre is the product of the amount of shrub per acre and the percentage rubber, and during the first year's growth in the nursery there is an inverse relation between these two factors. This is in agreement with a statement by Lloyd (18) that the rate of rubber secretion varies inversely with the rate of growth. In fact there is a considerable amount of data accumulating which indicates that almost any treatment which will restrict the vegetative growth but will allow the plant to maintain its photosynthetic area will result in an increase in rubber concentration, but not necessarily an increase in pounds of rubber per acre.

Plant samples were collected on December 13, 1943, for various anatomical studies by Addicott and Pankhurst (2). Included in their investigations were studies on the plant structure and the deposition of rubber, resin, and other materials in the various parts of the plant. They found that the plants grown under the high moisture stresses had increased deposition of rubber, lignin, and cellulose, and a considerable enlargement of the resin canals in comparison with those grown under low stresses. They also reported that, "In general, low moisture stress leads to enlargement of the tissues of the plants, with corresponding increases in the rubber-bearing capacity. High moisture stress leads to the accumulation of the products of photosynthesis." On the basis of their observations and the data presented above, it would seem not unreasonable to expect that a maximum yield of rubber might be obtained by growing guayule under low moisture stresses for a period of time long enough to produce a large shrub with a high potential rubber-bearing capacity and then subjecting it to a period of high moisture stresses in order to increase the percentage of rubber. The plants grown under low moisture stresses during 1943

are being subjected to high moisture stresses during 1944 in order to obtain some early indications as to whether or not this can be done.

GROWTH RESPONSES AFTER TRANSPLANTING

For guayule seedlings, as for all other plants that are grown in nurseries for transplanting, the most important criterion of nursery practices is the ability of the plants to resume growth quickly and to survive when set into the field, since, naturally, the crop yield is to a large degree dependent upon the stand of plants obtained. In the past it was the common practice of the Intercontinental Rubber Company to grow guayule transplanting stock with abundant water during the summer, to drought- and cold-harden it to some extent during the fall and winter, and to transplant it into the field in late winter and early spring. Experience showed that, for the type of stock produced, transplanting at this season resulted in maximum survival. With the transplanting program confined to this period, the principal criterion of "transplantable stock" was the crown-diameter of the plants. In a large planting program, such as was undertaken by the Emergency Rubber Project, it was necessary to extend the transplanting period over a considerable portion of the year. Depending to a considerable extent upon the season of transplanting, the growth responses of transplanted guayule have shown wide variations, resulting in field stands varying from as high as 90% to as low as 50%, even when soil and temperature conditions have not been unfavorable. Some plants have died and decayed soon after transplanting, others have resumed growth within a short time, and still others have been known to remain dormant for varying periods as long as a year after transplanting before resuming growth.[8]

The effects of previous moisture treatment upon the after-transplanting growth responses of the nursery stock grown in the present experiment were studied in an extensive transplanting program. At intervals during the period from September, 1943, to July, 1944, nine field transplanting trials were made with representative samples of plants, of a suitable caliper, from all treatments.

In preparation for transplanting, a sample of plants was dug (sometimes from dry soil without further irrigation) from each of the plots. These were obtained from areas of uniform dimension and from randomized locations within plots. Thirty plants[9] with a minimum crown-diameter of 5/32 inch were selected from each sample, except that in the case of the plots of treatment V a minimum of 4/32 inch was used in order to obtain per unit area a number of plants comparable to the number obtained in plots of the other treatments. At the first two transplantings the plants were topped to within 2 to 3 inches of the crown. In some cases this did not remove all the leaves, particularly from the plants of treatment V. Since Smith (28) has shown that the presence of leaves on the plant at the time of transplanting may

[8]For this reason, in the ensuing discussion the percentages of plants showing new growth at any particular time are not referred to as percentages of plants surviving.

[9]At the second transplanting only 18 plants were selected from each plot.

retard the resumption of growth, at all subsequent transplantings the plants were topped to within 1½ to 2 inches of the crown and all leaves were removed. It should be pointed out that under the conditions prevailing at the time of the first two transplantings the leaves remaining on the plants of treatment V apparently had little if any effect upon their resumption of growth. As will be seen later the plants from treatment V were the first to resume growth. Transplantings were made to randomized plots, by hand, within 72 hours after the plants were dug. The land was not pre-irrigated; and the first, second, third, sixth, seventh, eighth, and ninth transplantings were made to relatively dry soil. The fourth and fifth transplantings were made to wet soil and were soon followed by rain. At these dates the newly set plants were not irrigated. At all other transplanting dates the plants were irrigated within 24 hours after transplanting.

After each transplanting numerous counts were made to determine the number of plants that had initiated new growth. Data on the percentages of plants showing new growth[10] at varying periods of time after transplanting are presented graphically in Fig. 6 for the nine transplanting trials. The plotted data are the means of eight replicates of 30 plants each.[11] Analyses of variance[12] have been made on the data obtained at each counting of each transplanting, and in the following discussion only differences significant for a P value of 0.01 are spoken of as being significant.

For the first transplanting, made September 29, 1943, at all counting dates, the number of plants showing new growth was significantly higher for treatment V and significantly lower for treatment I than for any other treatment. Thirty-five days after transplanting, 96% of the treatment V plants showed new shoots or leaf growth, while for treatment I the value was only 19%. The values for the other three treatments at that time varied in the range from 60 to 70%. There were no significant differences between these treatments until the counting made on the 115th day. At that time, and at all subsequent countings, there were significant differences between all pairs of treatments.

At the first transplanting there were greater differences between the plants from the high and low moisture stress treatments than at any of the later transplantings, not only in the percentages of plants showing new growth but also in the type of growth resulting. The plants grown under high moisture stresses made a much more vigorous growth than did those grown under low moisture stresses. At the third counting, 35 days after transplanting, it was noted that most of the plants grown under the low moisture stresses, reported in the data as showing new growth, had only a few new buds. The plants of moisture treatment V were growing vigorously, had numerous leaves,

---

[10]Based on the numbers of plants actually present, growing, dormant, or dead, at each counting date. A few plants were removed by cultural operations and otherwise and their absence was taken into account in the calculations.

[11]At the second transplanting only 18 plants were selected from each plot.

[12]In cases where the error variances were not homogeneous for the different treatments as determined by the Chi-square test, the proper transformations were made before the analyses of variance were made. (Snedecor, George W. Statistical methods. Ames: The Iowa State College Press. 1940.)

and were already well established. The data, however, do not take these differences into consideration; both types of plants are reported simply as showing new growth.

As is apparent from the data of Fig. 6, when plants were taken for the first transplanting on September 28, the soil moisture stress on the plots of treatment I was still low, the moisture content to the 24-inch depth not having yet shown much decline and being still considerably above the wilting point. The plants of treatments II, III, and IV had been subjected to somewhat higher stresses, but the moisture content to the 24-inch depth had been at or below the wilting point for only a few days. In contrast, the plants of treatment V had been subjected to the high stresses of the wilting point range and below for several weeks. The soil moisture stresses of the plots of treatments I, II, III, and IV gradually increased up to the time of onset of the winter rains. It was thought that a gradual "hardening" of the more succulent plants would take place by reason of the increased moisture stresses and that their growth responses after transplantings would be improved thereby. This was tested by eight subsequent transplantings made at intervals during the winter, spring, and summer.

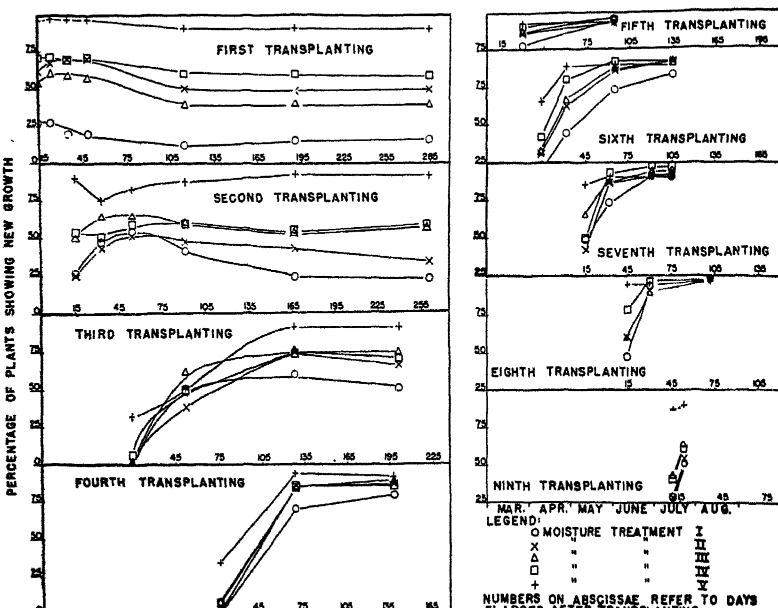

FIG. 6.—Percentages of plants showing new growth at varying periods of time after transplanting.

The second transplanting was made on October 22. After 15 days the percentage of plants showing new growth was significantly higher for treatment V than for any of the other treatments; treatments III and IV were significantly better than treatments I and II. At 33 days

after transplanting the percentage of plants showing new growth was significantly higher for treatment V than for treatments I, II, or IV.[13] The countings made on the 56th and 93rd days showed treatment V to be significantly better than any of the other treatments. At all subsequent counting dates significant differences existed between all treatment pairs, except for treatments III and IV. When counted after 265 days, the values for the surviving plants for treatments I, II, III, IV, and V were, in that order, 22, 33, 55, 56, and 93%.

The plants were set into the field for the third transplanting trial on December 1. After 14 days only 0.4% of the treatment I plants had evidences of new growth, while growth resumption had occurred in 32% of the plants of treatment V. At 15, 127, and 200 days after transplanting the values for treatment V were significantly higher than those of any other treatment. At all countings after 127 days from transplanting the values for treatment I were significantly lower than those of any other treatment. After 200 days 92% of the plants of treatment V had resumed growth. For treatment I the corresponding value was 53%. Treatments II, III, and IV with 68, 76, and 71%, respectively, did not differ significantly from each other.

January 25 was the date of the fourth transplanting. Only 0.8% of the treatment I plants had new shoots or leaves after 20 days, whereas 34% of the treatment V plants had resumed growth. After 142 days the value for treatment I had risen to 81%, that for treatment V to 92%. At the same date the percentages of plants showing new growth were, for treatments II, III, and IV, in that order, 88, 90, and 87. At all counting dates the values for treatment V were significantly greater than those for treatment I.

The fifth transplanting took place on March 8. After 30 days 93% of the plants of treatment V were growing. Treatment I, with 77% new growth, was significantly lower than any other treatment. After 93 days there were no significant differences between treatments.

The date of occurrence of the sixth transplanting was April 5.

[13]In the first two transplanting trials the values for percentages of plants showing new growth decrease with time. For the second transplanting the number of treatment V plants showing new growth after 33 days was less than the number reported at the 15-day count. This was probably due to an error in distinguishing new growth from the buds and leaves remaining on the plants at transplanting. A complete removal of leaf growth from the treatment V plants was not effected at the first two transplantings. On a few plants the leaves were still green after 15 days but not after 33 days. After the 15-day count special care was taken to distinguish new growth. Very little or no leaf growth remained on the plants of the other four treatments after they were topped for transplanting, yet the percentages of plants showing new growth show a greater decrease with time for these plants than for those of treatment V. The exact causes for this are unknown, but several factors are considered contributory. The values given are based on the number of plants actually present, growing, dormant, or dead, in each plot when the counts were made. The presence on the plant of any new bud was considered evidence of growth resumption. Injuries due to hoeing, cultivation, or rodents may have caused the death of some plants after they had been reported in earlier countings as having resumed growth. Possibly some of the plants grown under low moisture stresses, although able initially to put forth new buds, were not able to withstand the frosts and unfavorable growing conditions associated with winter weather at Salinas; possibly, also, these plants would not have been able to survive under any conditions.

Fifteen days later the percentages of plants with visible evidences of new growth were 20 and 65, respectively, for treatments I and V. After 105 days the values for treatments II, III, IV, and V had risen to 92–93%. Treatment I, with 84%, was significantly lower.

Sixteen days after the seventh transplanting, made on May 3, 86% of the treatment V plants had resumed growth as evidenced by new shoots and leaves, while 48% of the plants of treatment I showed a similar response. After 76 days the values for all treatments had risen to 91% or above and the differences between treatments were of no significance.

On June 2 plants from all plots were transplanted for the eighth time. When counted 15 days later, 95% of the treatment V plants had resumed growth as opposed to 47% for treatment I and 60, 61, and 79% for treatments II, III, and IV, in that order. After 34 days there were no significant differences, all values being above 92%.

The ninth transplanting was made on July 8. Ten days later 87% of the plants of treatment V showed new growth. The next highest values were 43% for treatment IV and 45% for treatment III, while only 30% of the plants of treatment I and II had produced new shoots or leaves. When counted after 17 days, 90% of the plants of treatment V and 49% of the plants of treatment I had new shoots or leaves. For treatments II, III, and IV, the values were 53, 64, and 60%, respectively.

Of the counts of plants showing new growth at various lengths of time after the several transplantings, the latest counts, made in June and July 1944, are thought to represent very closely the ultimate survival with the possible exception of the eighth and ninth transplantings. A summary of these counts, in terms of percentages, is given in the form of a graph in Fig. 7. These data give a good indication of the time required to "harden" succulent guayule nursery stock. While one or two months "hardening" by the withholding of water and by cold improved the after-transplanting growth responses of the succulent seedlings produced under low moisture stresses, under the conditions obtaining at Salinas during this experiment four to six months of "hardening" were required to bring about a percentage survival as high as for the plants grown under the high moisture stresses of treatment V.

It is of interest to note the relationship between the resumption of growth of the plants and the moisture stresses under which they were grown in the nursery. Equally satisfactory growth resumption of the plants of treatment V occurred at all seasons. Regardless of the time of transplanting, 91 to 93% of these plants grew, and in all cases they resumed growth more quickly than the plants of any other treatment, as is shown by Fig. 6. With increasing elapsed time between the cessation of irrigation and the date of transplanting, the growth responses of the plants grown under the low and medium moisture stresses of the first four treatments more and more closely approached those of the plants grown under the very high moisture stresses of treatment V. It was not until the fourth transplanting, in January, however, that the plants of the first four treatments survived transplanting at all satisfactorily, and it was not until the fifth

transplanting, in March, that their growth responses might be said to be as satisfactory as those of treatment V. Even at that date they resumed growth much more slowly (Fig. 6). Although all plots in the experiment received identical moisture applications after September 14, 1943, the effects of the differential moisture treatments which the plants had previously received were still evident more than 9 months later.

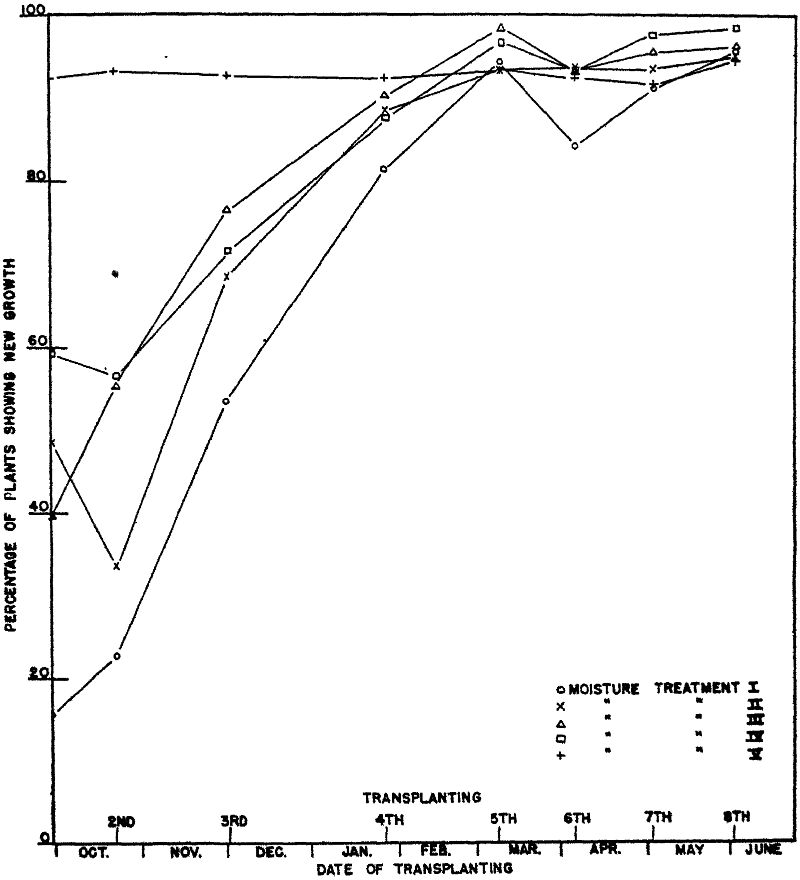

FIG. 7.—Percentages of plants showing new growth at the latest counting for the first eight transplantings.

The facts that more than 90% of the treatment V plants grew at whatever season transplanted and that in every case these plants resumed growth much more quickly than those of the other treatments are of outstanding practical importance, since they mean that guayule nursery stock can be produced with which transplantings can be made with satisfactory results over a large portion of the year. That guayule nursery stock can be grown which will survive trans-

planting throughout the year, provided that soil moisture and temperature conditions are not unfavorable, is of particular importance not only on irrigated land, but even more so in relation to plantings made on nonirrigated lands. In many "dry land" areas in California and the Southwest, where guayule is being grown or might be grown, rainfall is largely seasonal. In some cases the greater part of the yearly precipitation comes during the summer months; in others, during the winter. To establish guayule on such "dry land" areas would require that transplantings be made at the season when rainfall is adequate for the establishment of the plants. Conceivably, in order to do this, it might be necessary to transplant during any month of the year. In such an event it would be desirable to transplant stock which not only has a high ultimate survival but also is able to resume growth within the shortest possible time after transplanting. The ability of plants to initiate growth quickly after transplanting results in a maximum growing time during their first season in the field. It should also lower considerably the number of plants that succumb to disease, drought, and other factors which tend to reduce the stand in field plantings. Under conditions of high temperature, low humidity, and limited soil moisture, plants which quickly initiate growth and produce an extensive root system are able to obtain moisture from the maximum volume of soil and can be expected to show a higher ultimate survival and greater growth than plants which require a longer time for growth resumption. On the basis of the results of the present experiment, nursery stock grown under conditions of high moisture stress, as was that of treatment V, would be much more suitable for transplanting under "dry land" conditions than stock grown under low moisture stress.

It has been shown that guayule plants grown under high soil moisture stresses not only show a high survival, but are also quick to resume growth when transplanted. There are still other factors in favor of this type of nursery stock. When plants are grown under high moisture stresses, a minimum amount of irrigation water and fertilizers is required and the problem of weed control in the nursery is reduced to a minimum. All these factors tend to lower nursery production costs. The disease problems of guayule nursery seedlings are highly correlated with soil moisture content (20) and are very largely eliminated by growing the plants under conditions of high moisture stress. Plants grown under high moisture stresses, being smaller than plants produced with more abundant soil moisture, are more suitable for holding over in the nursery for transplanting during a second year should that for any reason be desirable.

Obviously the greater the ability of the plants to survive transplanting, the closer the approach to a perfect field stand and the greater the probability of the production of the highest possible yield of rubber per acre. The greater the proportion of available space occupied and shaded by guayule plants, the less the problem of field weed control. Weeds are a continuous problem in guayule fields having blank spots due to missing plants and their control is expensive.

OTHER CONSIDERATIONS

In addition to knowing the conditions under which guayule plants must be grown to obtain a rapid resumption of growth and a high survival, it would also be of interest to know the physiological condition of the plants that enables them to have these characteristics. The plants grown under the varying moisture stresses differ in many respects. Undoubtedly many of these differences are associated with their ability to survive and to resume growth quickly after transplanting. Certainly there are many factors which should be further investigated. Among these are the following: (a) The anatomy of the entire plant with special reference to the size and kinds of cells and tissues and the amount of lignification, cutinization, and suberization; (b) the amount and type of stored carbohydrates; and (c) the physico-chemical properties of the cell sap. It was not possible during this experiment to make a complete study of all of these factors. As was mentioned above, Addicott and Pankhurst (2) made certain investigations on the anatomy of some of the plants grown under the various moisture treatments. McRary and Traub (21) have reported that inulin is the main storage carbohydrate in guayule. They have made a study of the amount and type of stored carbohydrates in the plants grown under the various moisture stresses, and their observations indicate that there is a high correlation between the amount of inulin in the plant, during the fall of the year, and the moisture treatment. The inulin content varied from as low as 0.6% for plants receiving treatment I to above 9.0% for the plants receiving treatment V.

The anatomical studies and the tests on the amount and type of stored carbohydrates in guayule were made on samples which had been taken earlier in the summer and fall. This could not be done in the case of the physico-chemical measurements on the cell sap. These have to be made at the time the samples are taken. Measurements of this type will be made on a similar experiment being conducted in 1944. It is thought that the ability of a plant to survive transplanting may be correlated with the resistance of the plant to desiccation. It is known that the plants have to be "hardened" considerably before they will withstand transplanting, and that this "hardening off" treatment is similar to treatments which have been given other plants (5, 11, 19, 25) which have caused them to be resistant to desiccation. Much fundamental information is needed on the reasons why some plants will survive transplanting and resume growth quickly and other plants will not.

A considerable amount of work has been done in studying the transplanting of vegetable plants (5, 17, 19, 23, 29). Most of this work has laid emphasis upon the amount and type of growth produced after transplanting. There is very little information upon the survival of the transplanted plants grown under differential moisture stresses previous to transplanting. In the growing of vegetable plants there is evidently little difficulty in obtaining a satisfactory stand. Quite the opposite condition is true for ornamental shrubs, softwoods, and hardwoods. In many instances, with these types of plants, the

problem of survival is of major importance. Every year there are numerous transplantings made under various climatic conditions and often very low survivals of the transplanted plants are obtained. Since guayule is a woody plant, it would not be surprising if, in general, the results of this experiment would apply to other woody plants. It is not to be expected that all types of woody plants should be subjected to the same moisture stresses in order to produce the best planting stock. It is entirely possible, however, that the same fundamental principles would be involved.

SUMMARY

An experiment was conducted to determine the effects of soil moisture stresses, ranging from very high to very low, on the amount and type of growth in the nursery and the after-transplanting growth responses of guayule nursery stock.

Guayule plants grown under high moisture stresses in the nursery in comparison with plants grown under low moisture stresses (a) produced significantly less vegetative growth; (b) when transplanted, resumed growth more quickly, grew more vigorously, and in fall transplantings had much higher percentage survival; (c) were comparatively better able to withstand unfavorable conditions after transplanting; and (d) had higher rubber and lignin contents, and in the fall had higher inulin contents.

Guayule plants grown under high moisture stresses in the nursery can be transplanted with satisfactory results any time of the year provided soil moisture and temperature conditions are favorable. Four to six months of "hardening" were required under the conditions of this experiment to bring about as high survival after transplanting for plants grown under low moisture stresses as obtained with plants grown under high moisture stresses.

Under the conditions of this experiment there was little difference in the depth of root penetration by plants grown under high and low moisture stresses.

The guayule nursery seedlings obtained their water from the soil to the depth of root penetration. In this experiment, during the first year, this depth was 42 to 48 inches. While the soil moisture was at a low tension near the surface, water was absorbed almost entirely in this region. When the topsoil approached the wilting point the water was absorbed from the lower depths.

LITERATURE CITED

1. ADAMS, FRANK, VEIHMEYER, F. J., and BROWN, FLOYD N. Cotton irrigation investigations in San Joaquin Valley, Calif., 1926 to 1935. Calif. Agr. Exp. Sta. Bul. 668. 1942.
2. ADDICOTT, FREDERICK T., and PANKHURST, JEAN. Some anatomical effects of moisture stress in nursery seedlings of guayule. Bot. Gaz., 106:208-214. 1944.
3. ALDRICH, W. W., LEWIS, M. R., WORK, R. A., RYALL, A. L., and REIMER, F. C. Anjou pear responses to irrigation in a clay adobe soil. Ore. Agr. Exp. Sta. Bul. 374. 1940.

4. AYERS, A. D., WADLEIGH, C. H., and MAGISTAD, O. C. The interrelationships of salt concentration and soil moisture content with the growth of beans. Jour. Amer. Soc. Agron., 35:796–810. 1943.

5. BABB, M. F. Residual effects of forcing and hardening of tomato, cabbage, and cauliflower plants. U. S. D. A. Tech. Bul. 760. 1940.

6. BECKETT, S. H., and DUNSHEE, CARROLL F. Water requirements of cotton on sandy loam soils in Southern San Joaquin Valley. Calif. Agr. Exp. Sta. Bul. 537. 1932.

7. BOUYOUCOS, G. J., and MICK, A. H. An electrical resistance method for the continuous measurement of soil moisture under field conditions. Mich. State College Tech Bul. 172. 1940.

8. DAVIS, CHARLES HOMER. Responses of *Cyperus Rotundus* L. to five moisture levels. Plant Physiol., 17:311–316. 1942.

9. FURR, J. R., and TAYLOR, C. A. Growth of lemon fruits in relation to moisture content of the soil. U. S. D. A. Tech. Bul. 640. 1939.

10. GEORGE, ERNEST J. Tree planting on the drier sections of the northern Great Plains. Jour. Forestry, 37:695–698. 1939.

11. GREATHOUSE, GLENN A., and STUART, NEIL W. A study of the physical and chemical properties of red clover roots in the cold-hardened and unhardened condition. Md. Agr. Exp. Sta. Bul. 370:147-165. 1934.

12. HENDRICKSON, A. H. and VEIHMEYER, F. J. Irrigation experiments with peaches in California. Calif. Agr. Exp. Sta. Bul. 479. 1929.

13. ——————, ——————. Irrigation experiments with prunes. Calif. Agr. Exp. Sta. Bul. 573. 1934.

14. ——————, ——————. Irrigation experiments with pears and apples. Calif. Agr. Exp. Sta. Bul. 667. 1942.

15. ——————, ——————. Readily available soil moisture and sizes of fruits. Proc. Amer. Soc. Hort. Sci., 40:13–18. 1942.

16. Intercontinental Rubber Company. Unpublished data and records; now in possession of Emergency Rubber Project, U. S. D. A., Salinas, Calif.

17. KRAUS, JAMES E. Effects of partial defoliation at transplanting time on subsequent growth and yield of lettuce, cauliflower, celery, peppers, and onions. U. S. D. A. Tech. Bul. 829. 1942.

18. LLOYD, FRANCIS ERNEST. Guayule, a rubber-plant of the Chihuahuan desert. Carnegie Inst. Wash. Pub. No. 139. 1911. (Reprinted in 1942.)

19. LOOMIS, W. E. Studies in the transplanting of vegetable plants. Cornell Univ. Agr. Exp. Sta. Mem. 87. 1925.

20. Pathology Division, Special Guayule Research Project. Guayule nursery diseases and their control. Mimeographed report. May 1944.

21. MCRARY, WILLARD, and TRAUB, HAMILTON P. Fructosan, a reserve carbohydrate in guayule, *Parthenium argentatum* Gray. Science, 99:435–436. 1944.

22. RICHARDS, L. A. Soil moisture tensiometer materials and construction. Soil Sci., 53:241–248. 1942.

23. ——————. Pressure-plate apparatus for measuring soil moisture sorption and transmission by soils. Soil Sci., 56:395–404. 1943.

24. ROGERS, W. S. The relations of soil moisture to plant growth, illustrated by moisture meter experiments with strawberries. Ann. Rpt. East Malling Res. Sta., 111–120. 1935.

25. ROSA, J. T., JR. Investigations on the hardening process in vegetable plants. Mo. Agr. Exp. Sta. Res. Bul. 48:1–97. 1921.

26. SCHNEIDER, G. WILLIAM, and CHILDERS, N. F. Influence of soil moisture on photosynthesis, respiration and transpiration of apple leaves. Plant Physiol., 16, 565–583. 1941.

27. SHIRLEY, HARDY L., and MEULI, LLOYD J. Influence of moisture supply on drought resistance of conifers. Jour. Agr. Res., 59:1–21. 1939.

28. SMITH, PAUL F. Inhibition of growth in guayule as affected by topping and defoliation. Amer. Jour. Bot., 31:328–336. 1944.

29. THOMPSON, HOMER C. Vegetable crops. New York: McGraw-Hill Book Co., Inc. 1923.

30. U. S. Dept. of Commerce, Weather Bureau. Climatological Data, California Section. Vols. XLVII, XLVIII. 1943; 1944.

31. VEIHMEYER, F. J. Method of determining permanent wilting percentage of soils. Univ. of Calif., College of Agriculture, Davis, Calif. Private communication.
32. ————, EDLEFSEN, N. E., and HENDRICKSON, A. H. Use of tensiometers in measuring availability of water to plants. Plant Physiol., 18:66–78. 1943.
33. ———— and HENDRICKSON, A. H. Essentials of irrigation and cultivation of orchards. Calif. Agr. Ext. Service Circ. 50. 1930. (Revised in 1943).
34. ————, ————. The moisture equivalent as a measure of the field capacity of soils. Soil Sci., 32:181–193. 1931.

SEED AND SEEDLING CHARACTERS IN CERTAIN VARIETIES OF SOYBEANS[1]

C. S. DORCHESTER[2]

WITH THE increasing use of soybeans in the cornbelt the problems of soybean management are becoming steadily more important. One of the problems which is attracting much attention is the choice of varieties. A desirable soybean variety should carry a high percentage of oil, stand up well, be high yielding and non-shattering, and should be adapted in maturity to the locality in which it is to be grown.

To meet the annual planting needs of the Corn belt area several million bushels of seed are required. Growers and seed dealers naturally are interested in this demand for seed and are attempting to handle desirable varieties for the localities in which their customers reside. Experiment stations, in cooperation with the U. S. Dept. of Agriculture, are isolating and testing new kinds. All of these factors are pushing the matter of varietal identification into especial prominence.

Soybean varieties, both of the established and of the newer kinds, in many instances resemble each other so closely in seed characters that identification by these characters alone is difficult. Additional differences as might be observed in the seedling stage and therefore rather quickly determined, as well as a more detailed description of seed characters, apparently would be useful.

In the late fall of 1942, 27 varieties of soybeans, most of them already commercially important in the Corn Belt or showing considerable promise as new kinds, were obtained in small lots from the Iowa and Indiana Agricultural Experiment Stations. Again, in 1943, different lots of the same varieties were obtained from the Agricultural Experiment Stations in Illinois and Iowa. These lots then were hand picked to eliminate damaged seeds and to obtain samples uniformly true to the indicated varietal type.

An examination of the seed characters in this group indicated that many of these varieties are similar. Some of them appear so nearly identical that identification on the seed basis alone is difficult if not impossible. As a result of a comparative study the following seed key has been developed.

SEED CLASSIFICATION

I. Seed yellow
  A. Hilums large, 3 or more mm in length
    1. Hilums black, with narrow white scar

[1]Contribution from the Farm Crops Subsection, Iowa Agricultural Experiment Station, Ames, Iowa. Journal paper J-1242. Project 164. Received for publication November 10, 1944.

[2]Associate Professor of Farm Crops. Robert Weber of the U. S. Dept. of Agriculture and Professor H. D. Hughes and Doctor I. J. Johnson of Iowa State College, made valuable suggestions in connection with this study.

a. Hilum margins[3] greenish black to black
B. H. Manchu, Lincoln, Mandell, Manchu 606, Mingo, Ontario, Scioto, Wis. Manchu 3, Wis. Manchu 3 (Sel.)

b. Hilum margins brown
Mt. Carmel, Patoka

2. Hilums black or brown, variable, enclosing wide white scar, seed small, ellipsoidal
Midwest

B. Hilums small, less than 3 mm. in length

1. Hilums black, or brown with narrow longitudinal bar of black, margins faintly brown to brown
Chief

2. Hilums other than black

a. Hilums brown or buff

1). Hilums dark brown with wide white scar, small and ellipsoidal
Minsoy

2). Hilums buff, sometimes almost brown

a). Seed strongly tinged with brown
Seneca

b). Seed not tinged with brown
Boone, Illini, Macoupin, Mukden

c). Seed pale yellow, almost white[4]
Dunfield

b. Hilums slate or gray
Richland

c. Hilums not colored, or very faintly tinged with buff

1). Hilums very faintly tinged with buff, seed pale yellow
Gibson

2). Hilums not colored

a). Seed medium to small, globose to ellipsoidal

(1). Pigmented spot over tip of radicle generally present
Earlyana

(2). Pigmented spot over tip of radicle generally absent
Mandarin

b). Seed distinctly large, uniformly ellipsoidal
Habaro, OAC 211

II. Seed black and distinctly flattened
Kingway, Peking

SEEDLING STUDY

On January 20, 1943, the 27 samples were planted in the greenhouse in 2-gallon crocks filled with a mixture of two-thirds soil and one-third sand, each variety in a separate crock. Stands of 20 to 25 plants were obtained in each instance and these were thinned to 10 plants per crock. Varieties planted were as follows:

---

[3]Hilum margin refers to that part of the seedcoat adjacent to and surrounding the hilum area.

[4]Samples of Dunfield will not necessarily exhibit this character.

Black Hilum Manchu	Macoupin	Ontario
Boone	Mandarin	Patoka
Chief	Mandell	Peking
Dunfield	Midwest	Richland
Gibson	Mingo	Scioto
Habaro	Minsoy	Seneca
Illini	Mt. Carmel	Wis. Manchu 3
Kingwa	Mukden	Wis. Manchu 3 (Sel.)
Lincoln	OAC 211	Wis. Manchu 606

During the winter of 1943–44 the seedling study of the foregoing varieties, with the addition of Earlyana, was repeated with new lots of seed obtained from a different source. The seed was dusted with Arasan and plantings made on February 24, 1944.

In the seedling study the following varietal differences were observed: (1) Mesocotyl color (purple vs. green) evident at time of emergence; (2) shape of the unifoliate leaves, observable 2 to 3 weeks after planting; (3) shape of the trifoliate group, observable 3 to 4 weeks after planting.

With respect to the leaf and leaflet shape in items Nos. 2 and 3, the following differences were observed: (a) Shape of the basal lobes; (b) shape of the apex; (c) width relative to length. (See Fig. 1).

In the following description the seedling characters listed are those which appear to be useful in the identification of the variety. It will be noted, however, that in many instances the seedling differences given are not sufficient to distinguish the variety from certain others of the same seed group. In connection with the description of the unifoliate leaves and of the apical leaflets of the trifoliate type, the term "long" indicates that the leaf, or leaflet, is distinctly longer than wide, while the term "short" indicates that the width dimension is approximately equal to that of the length. The term "Seed Group" includes those varieties having similar seed characteristics. For the seed groups including more than two varieties, a key based upon seedling characters is included.

SEED GROUP: B. H. MANCHU, LINCOLN, MANCHU 606, MANDELL, MINGO, ONTARIO, SCIOTO, WIS. MANCHU 3, WIS. MANCHU 3 (SEL.)

I. Mesocotyl purple
  A. Unifoliate leaf base indented
    1. Unifoliate leaf long
      a. Unifoliate leaf tapering, tip rounded
        1) Apical leaflet long
          a) Apical leaflet tip pointed
            B. H. Manchu, Mingo
          b) Apical leaflet tip rounded
            Manchu 606, Mandell
        2) Apical leaflet short, tip rounded
            Wis. Manchu 3, Wis. Manchu 3, (Sel.)
    2. Unifoliate leaf short, tip slightly indented
            Ontario

B. Unifoliate leaf base square, leaf long, tapering
Scioto

II. Mesocotyl green, unifoliate leaf long, base slightly elongated
Lincoln

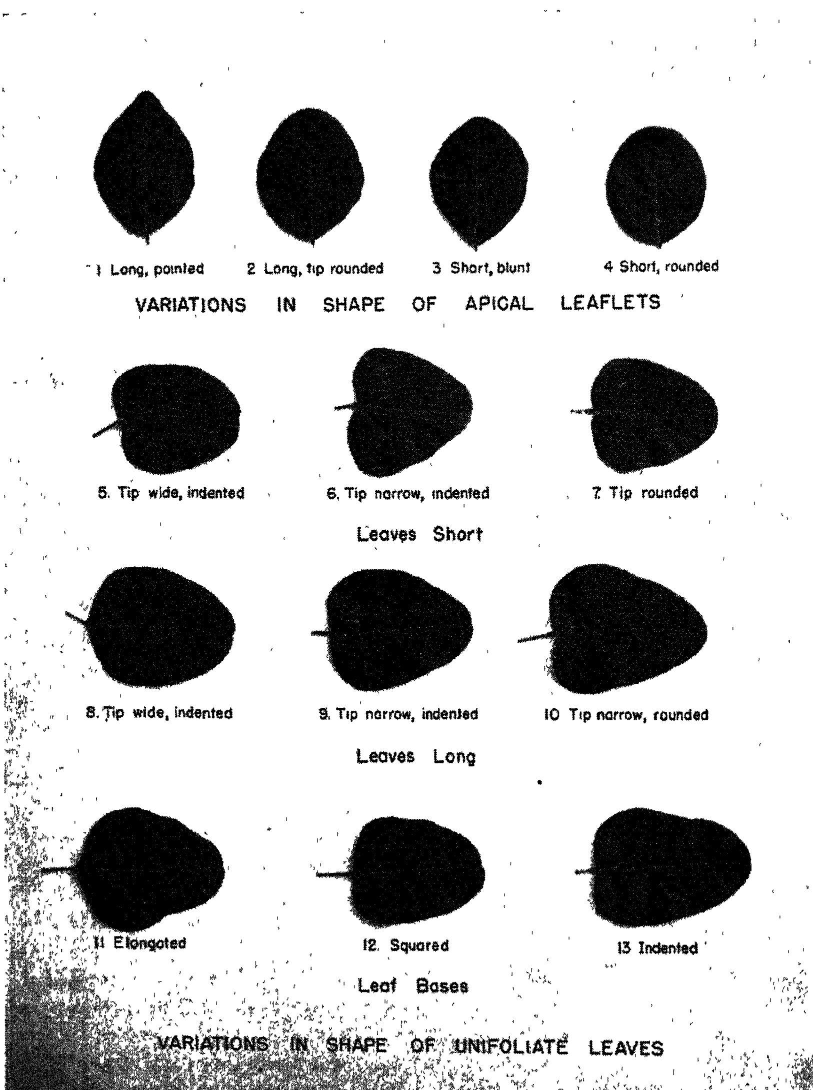

FIG. 1.—Illustrating variations in the shape of apical leaflets and unifoliate leaves, useful in identifying certain varieties of soybeans when in the seedling stage of growth.

DESCRIPTION OF SEEDLING CHARACTERS

B. H. Manchu (Fig. 2).—Mesocotyl purple; unifoliate leaf long, tapering toward a rounded tip, base indented; apical leaflet long, tapering toward a pointed tip; lateral leaflet long, tapering toward a pointed tip.

Lincoln (Fig. 2).—Mesocotyl green; unifoliate leaf long, tip blunt and one sided, base slightly elongated; apical leaflet long, rounded, tip rounded to slightly indented; lateral leaflet long, rounded, tip wide and rounded.

Manchu 606 (Fig. 2).—Mesocotyl purple; unifoliate leaf long, tapering toward a rounded tip, base indented; apical leaflet long, rounded, tip rounded; lateral leaflet short, rounded, tip rounded.

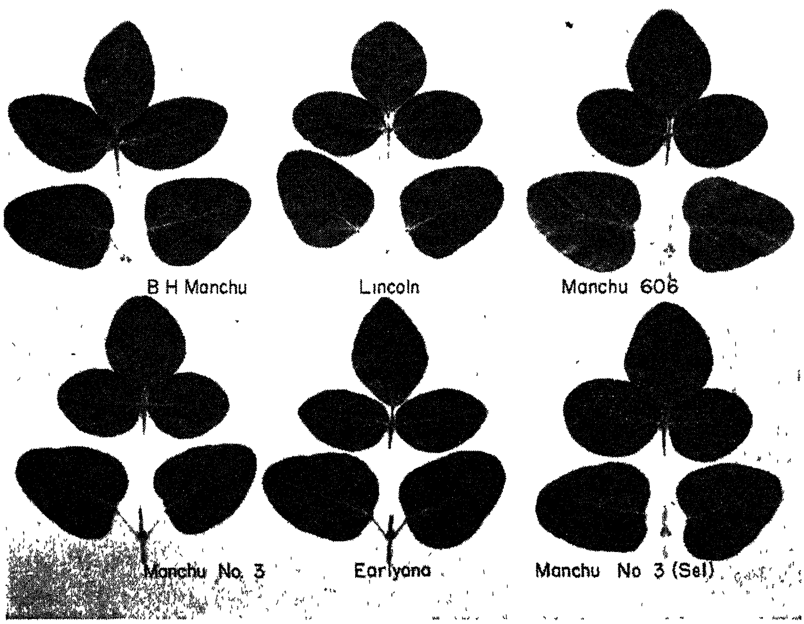

FIG. 2.—The characteristic shape of apical leaflets and of unifoliate leaves of six varieties of soybeans.

Mandell (Fig. 3).—Mesocotyl purple; unifoliate leaf long, tapering toward a rounded tip, base indented; apical leaflet long, rounded, tip rounded; lateral leaflet long, tip wide and rounded.

Mingo (Fig. 3).—Mesocotyl purple; unifoliate leaf long, tapering toward a rounded tip, base square to indented; apical leaflet long, tapering toward a pointed tip; lateral leaflet long, tip wide and rounded.

Ontario (Fig. 3).—Mesocotyl purple; unifoliate leaf short, tapering toward a slightly indented tip, base indented; apical leaflet rounded, base and tip distinctly rounded; lateral leaflet rounded, base and tip distinctly rounded.

Scioto (Fig. 3).—Mesocotyl purple; unifoliate leaf long, tapering toward a rounded tip, base squared; apical leaflet short, rounded; lateral leaflet short, rounded.

Wis. Manchu 3 (Fig. 2).—Mesocotyl purple; unifoliate leaf long, tapering toward a rounded tip, base indented; apical leaflet short, rounded, tip wide and rounded; lateral leaflet short and rounded.

Wis. Manchu 3 (Sel.) (Fig. 2).—Mesocotyl purple; unifoliate leaf long, tapering toward a rounded tip, base indented; apical leaflet short, rounded, tip wide and rounded; lateral leaflet short and distinctly rounded.

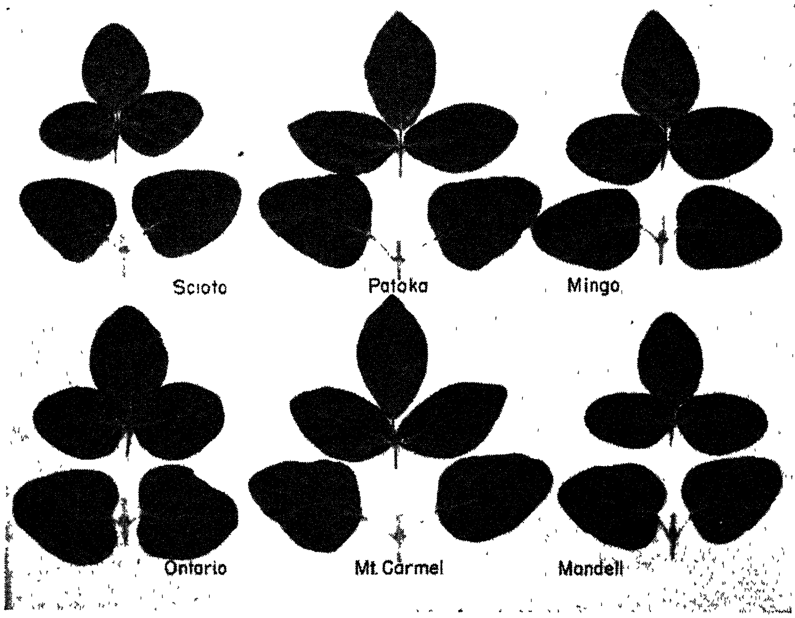

FIG. 3.—The characteristic shape of apical leaflets and of unifoliate leaves of six varieties of soybeans.

SEED GROUP: MT. CARMEL, PATOKA

Mt. Carmel (Fig. 3).—Mesocotyl purple; unifoliate leaf long, tapering toward a rounded tip, base elongated; apical leaflet long, narrow and sharply pointed; lateral leaflet long, narrow and sharply pointed.

Patoka (Fig. 3).—Similar to Mt. Carmel and apparently the same variety.

SEED GROUP: BOONE, ILLINI, MACOUPIN, MUKDEN, DUNFIELD

I. Mesocotyl green
  A. Unifoliate leaf base indented
    1. Unifoliate leaf long
      a. Unifoliate leaf tapering
        1) Unifoliate leaf tip slightly indented
          a) Trifoliate leaflets long, tapering
            Boone, Dunfield
          b) Trifoliate leaflets short, rounded
            Macoupin

2. Unifoliate leaf short, tip wide and slightly indented
Illini

B. Unifoliate leaf base elongated, leaf tip wide and indented
Mukden

DESCRIPTION OF SEEDLING CHARACTERS

Boone (Fig. 5).—Mesocotyl green; unifoliate leaf long, tapering toward a slightly indented tip, base strongly indented; apical and lateral leaflets long, rounded at base and tip.

Dunfield (Fig. 4).—Mesocotyl green; unifoliate leaf long, tapering to a slightly indented tip, base indented; apical leaflet long, base tapered to rounded, tip rounded; lateral leaflet long, base tapered to rounded, tip rounded.

Illini (Fig. 4).—Mesocotyl green; unifoliate leaf short, tip wide and slightly indented, base squared to indented; apical leaflet short, rounded, tip narrow and rounded; lateral leaflet long, rounded, tip rounded.

Macoupin (Fig. 4).—Mesocotyl green; unifoliate leaf long, tapering to an indented tip, base indented; apical leaflet short, rounded, tip wide, rounded to indented; lateral leaflet short, rounded, tip wide and rounded.

Mukden (Fig. 4).—Mesocotyl green; unifoliate leaf long, tip wide, indented, base elongated; apical leaflet obovate, tip blunt to rounded; lateral leaf long, tip blunt to rounded.

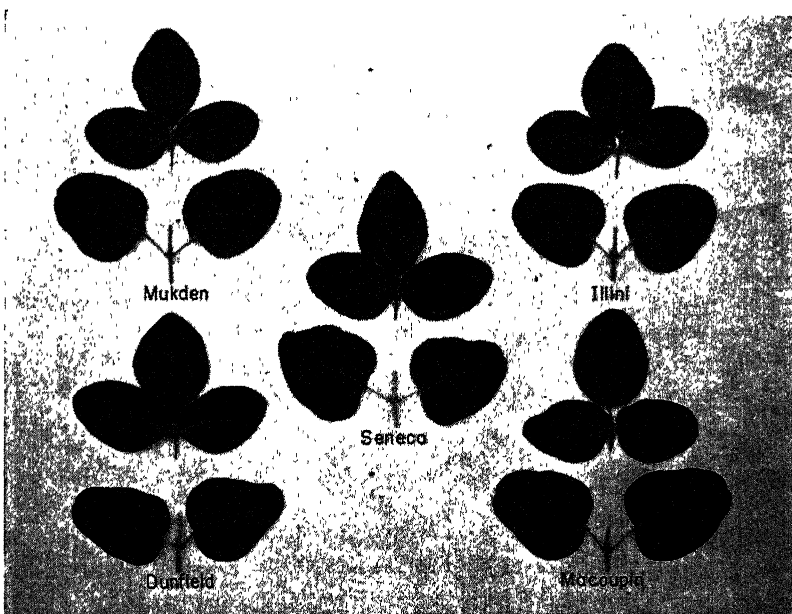

FIG. 4.—The characteristic shape of apical leaflets and of unifoliate leaves of five varieties of soybeans.

SEED GROUP: HABARO, OAC 211[5]

Habaro (Fig. 6).—Mesocotyl purple; unifoliate leaf *extremely wide and short, tip wide*, indented, and usually one-sided, base squared; apical leaflet distinctly short, rounded, tip wide and rounded; lateral leaflet long, rounded, tip wide and rounded.

OAC 211 (Fig. 6).—Mesocotyl purple; unifoliate leaf *long, tip narrow*, indented, and distinctly one-sided, base squared; apical leaflet short, obovate to rounded; lateral leaflet long, rounded at base and tip.

SEED GROUP: EARLYANA, MANDARIN

Earlyana (Fig. 2).—Mesocotyl purple; unifoliate leaf *long, tapering to a rounded tip, base squared; apical* and lateral *leaflets long*, tapering to a pointed tip.

Mandarin (Fig. 6).—Mesocotyl purple; unifoliate leaf *short, tip wide, indented, base elongated; apical leaflet short, rounded at base and tip;* lateral leaflet long, rounded at base and tip.

SEED GROUP: KINGWA, PEKING

Kingwa (Fig. 5).—Mesocotyl *purple;* unifoliate leaf short, tip wide, indented, base square to indented; apical leaflet short and distinctly rounded; lateral leaflet short, tapering toward a rounded tip.

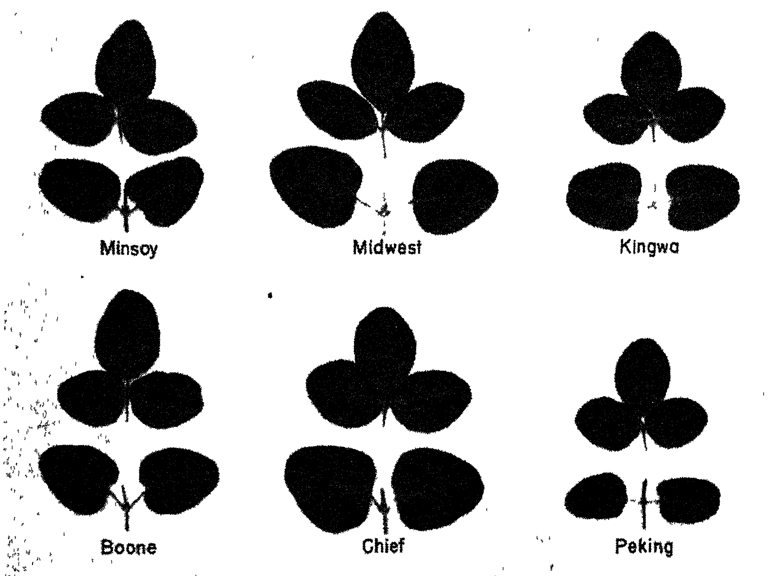

FIG. 5.—The characteristic shape of apical leaflets and of unifoliate leaves of six varieties of soybeans.

[5]Italics indicate distinctive characters within the seed group.

Peking (Fig. 5).—Mesocotyl *green;* unifoliate leaf small, distinctly oblong, tip indented, base square to indented; apical leaflet slightly elongated, rounded toward base and tip; lateral leaflet small and rounded.

The following varieties may be identified by their seed characters and therefore are not listed here in seed groups.

Chief (Fig. 5).—Mesocotyl purple; unifoliate leaf short, tapering toward an indented tip, base squared; apical and lateral leaflets short, rounded at base and tip.

Gibson (Fig. 6).—Mesocotyl green; unifoliate leaf long, tapering toward a rounded tip, base squared to elongated; apical leaflet long, tapered toward base, tip blunt; lateral leaflet long, tapered toward base and tip.

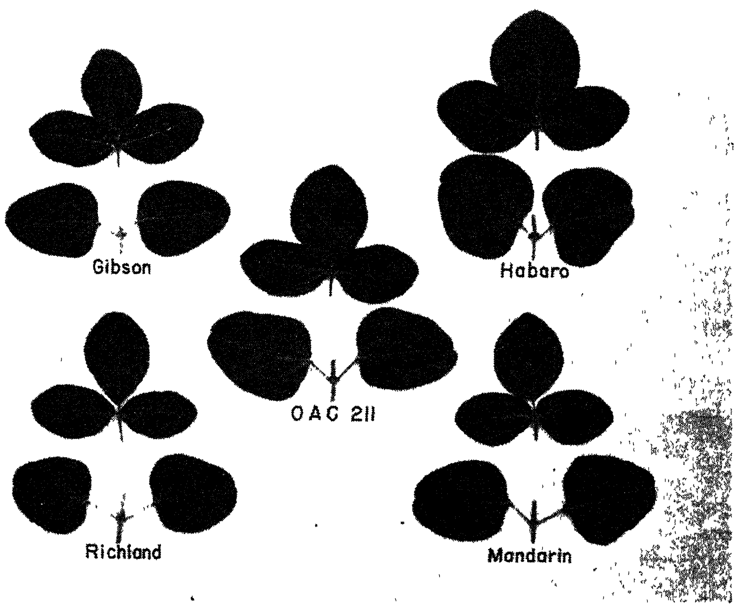

FIG. 6.—The characteristic shape of apical leaflets and of unifoliate leaves of five varieties of soybeans.

Midwest (Fig. 5).—Mesocotyl purple; unifoliate leaf long, rounded toward a rounded tip, base squared to indented; apical and lateral leaflets long, tapered toward base and tip, tip rounded.

Minsoy (Fig. 5).—Mesocotyl purple; unifoliate leaf long, tapered toward a slightly indented tip, base rounded to elongated; apical leaflet long, tapered toward a pointed tip; lateral leaflet long, tapered toward a rounded tip.

Richland (Fig. 6).—Mesocotyl purple; unifoliate leaf short, tip wide and slightly indented, base squared; apical leaflet long, tapered toward base, tip wide and rounded; lateral leaflet tapered toward base and tip.

Seneca (Fig. 4).—Mesocotyl green; unifoliate leaf short, tapered toward an indented tip, base squared; apical leaflet long, tapered toward a rounded tip; lateral leaflet long and rounded, tip rounded.

SUMMARY

As was to be expected, the leaf and leaflet shapes vary considerably within the variety, and the leaflets often vary somewhat on the same plant. As a rule, however, the plants of a variety exhibit definite leaf shape characters which, in several instances, may be used to distinguish that variety from others having similar seed characters. For example, of the Boone, Illini, Macoupin, Mukden, and Dunfield group, Mukden alone has the unifoliate leaves with distinctly elongated bases (Figs. 4 and 5). Also, in the two seed groups characterized by large black hilums with narrow white scar, including 11 varieties, Patoka and Mt. Carmel may be distinguished from the others by their markedly long and pointed leaflets (Fig. 3), and again Manchu 606, Manchu 3, and Manchu 3 (Sel.) may be identified as a group by their distinctly short and rounding leaflets (Fig. 2).

The mesocotyl color is especially useful in two instances. Of the 11 varieties in the seed groups with large black hilums, Lincoln may be distinguished by its green mesocotyl, all of the others having the purple character. Peking and Kingwa, the two black-seeded varieties studied, differ in mesocotyl color, Peking being green and Kingwa purple.

Under the conditions of this test, pubescence color could not be definitely determined until approximately 7 weeks after planting. Until this time, most of the varieties appeared to have a gray pubescence. The exceptions, B. H. Manchu, Ontario, and Midwest, exhibited a distinctly tawny pubescence as early as 4 weeks after planting. The pubescence color apparently will be of little or no use in connection with the identification of soybean varieties in the seedling stage.

MILLING, BAKING, AND CHEMICAL PROPERTIES OF MARQUIS AND KANRED WHEAT GROWN IN COLORADO AND STORED 14 TO 22 YEARS[1]

C. C. FIFIELD AND D. W. ROBERTSON[2]

THE QUALITY characteristics of various lots of Marquis and Kanred wheat varieties grown in Colorado and stored for different periods of years were reported in 1938 (3).[3] Portions of these have been continued under storage and were sampled again in the spring of 1943 (after 14 to 22 years' storage) for milling, baking, and germination tests. Thiamine assays on the wheat flour and the bread by the fungus method (1) also were made of the 1943 samples by Dr. K. C. Hammer of the U. S. Regional Plant, Soil, and Nutrition Laboratory, Agricultural Research Administration, Ithaca, N. Y., to whom the writers are indebted for the data reported in this paper.

SOURCES OF SAMPLES

The wheats studied were grown at the Colorado Agricultural Experiment Station, on experimental plots and stored in a dry, unheated room at Fort Collins, Colo., for periods varying from 14 to 22 years as reported by Robertson, *et al.* (4). The samples consisted of the variety Marquis from each of nine crop years from 1921 to 1927, inclusive, and of the 1929 and 1942 crops; and the variety Kanred from each of the three crop years 1921, 1924, and 1929. In the later years of storage there was considerable damage to the grain by the dermestid beetle, *Trogoderma tarsale*. The grain was cleaned at least once in 2 years over a fanning mill to remove damaged kernels and the storage room was sprayed with ethylene dichloride-carbon tetrachloride mixture after each cleaning to control insect pests.[4]

METHODS

Milling and baking experiments were conducted in the laboratories of the Grain Products Branch, Office of Distribution, War Food Administration, Beltsville, Md. The tempered wheats were milled on an Allis-Chalmers experimental flour mill provided with three pairs of break rolls and one pair of smooth rolls.[5] None of the lots required special tempering treatment or unusual milling technic for the production of satisfactory flour. Chemical tests (moisture, ash, and protein) were made by accepted and approved methods of the American Association of Cereal Chemists.[6] Acidity was determined on the extracted fat constituents

[1]Contribution from the Colorado Agricultural Experiment Station, Fort Collins, Colo., the Division of Cereal Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. Department of Agriculture; and the Grain Products Branch, Office of Distribution, War Food Administration. Authorized by the Director of the Colorado Agricultural Experiment Station for publication as Scientific Journal Series Article No. 189. Received for publication December 15, 1944.

[2]Baking Technologist, Division of Cereal Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering, and Agronomist, Colorado Agricultural Experiment Station, respectively. Credit is due Ray Weaver, J. F. Hayes, E. Hoffecker, T. Hartsing, and B. E. Rothgeb, Office of Distribution, War Food Administration, for making some of the determinations reported in this paper.

[3]Figures in parenthesis refer to "Literature Cited". p. 239.

[4]The mixture used was ethylene dichloride 3 parts, carbon tetrachloride 1 part by volume, according to Roark and Cotton (2).

[5]For complete description of milling equipment and operative technic see U. S. D. A. Tech Bul. 197, 1930.

[6]Cereal laboratory methods published by the American Association of Cereal Chemists, 4th ed. 1941.

TABLE 1.—*Quality data on the milling, baking, and certain other properties of Marquis (irrigated) and Kanred (not irrigated) wheat after storage for various periods (14–22 years) grown and stored at Colorado State College, Fort Collins, Colorado.*

Variety and year grown	1921 Marquis		1922 Marquis		1923 Marquis		1924 Marquis		1925 Marquis		1926 Marquis	
Year tested	1938	1943	1938	1943	1938	1943	1938	1943	1938	1943	1938	1943
Analysis of wheat:												
U. S. grade*	3 DNS	1 DNS	2 DNS	1 HDNS	4 DNS	1 DNS	3 NS	1 HNS	4 NS	4 NS	3 DNS	1 HDNS
Test weight, lbs.†	59.2	58.4	61.5	60.9	60.0	59.2	62.4	61.8	57.1	56.6	63.1	62.3
Flour yield, %‡	70.7	72.0	72.7	71.9	70.6	70.4	72.3	71.0	69.3	67.5	73.7	72.9
Protein, %	14.4	14.0	13.7	13.7	13.6	13.4	12.6	12.3	11.3	11.2	12.6	12.8
Ash, %§	1.74	1.76	1.56	1.63	1.74	1.67	1.64	1.59	1.84	1.70	1.48	1.41
Moisture, %	10.7	12.1	11.0	12.2	10.5	12.4	10.4	12.4	10.5	12.5	10.6	12.2
Fat acidity**	47.7	57.3	42.8	52.9	47.4	61.2	34.8	44.4	43.2	52.3	32.4	44.4
Increase in fat acidity, 1938 to 1943, %	—	21		24		29		28		21		37
Analysis of flour:												
Protein, %§	13.6	13.4	13.1	12.6	12.7	12.9	11.7	11.5	10.8	10.6	12.1	11.9
Ash, %§	0.43	0.59	0.40	0.51	0.43	0.54	0.44	0.44	0.45	0.51	0.40	0.43
Gassing power, mm:												
1st hour	84	88	79	87	66	71	85	91	80	88	85	91
2d hour	129	134	89	99	68	79	107	113	121	128	110	119
3d hour	60	95	17	21	14	16	21	24	80	85	21	25
Total	273	317	185	207	148	166	213	228	281	301	216	235
Bread:												
Absorption, %	64.0	64.0	64.0	64.0	64.0	64.0	64.0	64.0	64.0	64.0	64.0	64.0
Loaf volume, cc:												
Commercial	709	709	604	600	672	654	583	576	622	598	610	592
Com. + 1 mg bromate	684	746	604	628	650	666	577	609	577	614	595	606
Com. using 3% yeast	661	729	604	592	616	629	557	576	619	615	583	562
Average	684	728	604	606	646	649	572	587	606	609	596	586
Grain and texture:												
Commercial	85VG	85VG	70G	75G	90VG	85G	75G	75G	80G	80G	80G	75G
Com. + 1 mg bromate	90VG	95VG	75G	85G	80G	90VG	75G	80G	80G	80G	85G	80G
Com. using 3% yeast	80VG	90VG	70G	80G	85VG	85G	70G	75G	80G	85G	75G	70G
Color of crumb:												
Commercial	95Cr	80Cr	75Cr	80Cr	90Cr	85Cr	85Cr	80Cr	85Cr	80Cr	90Cr	80Cr
Com. + 1 mg bromate	90Cr	95Cr	80Cr	90Cr	85Cr	90Cr	80Cr	85Cr	80Cr	85Cr	85Cr	80Cr
Com. using 3% yeast	85Cr	90Cr	75Cr	75Cr	90Cr	75Cr	70Cr	75Cr	75Cr	80Cr	80Cr	70Cr
Single figure value:												
Commercial	97.0	96.0	66.0	67.0	90.0	81.0	64.0	62.0	73.0	68.0	71.0	65.0
Com. + 1 mg bromate	93.0	107.0	68.0	76.0	79.0	89.0	62.0	71.0	63.0	72.0	69.0	69.0
Com. using 3% yeast	85.0	102.0	66.0	66.0	78.0	75.0	55.0	61.0	72.0	73.0	64.0	56.0

Variety and year grown	1927 Marquis		1929 Marquis		1942 Marquis	1921 Kanred		1924 Kanred		1929 Kanred	
Year tested	1938	1943	1938	1943	1943	1938	1943	1938	1943	1938††	1943
Analysis of wheat:											
U. S. grade*	2 DNS	1 DNS	1 HDNS	1 HDNS	1 HDNS	3 DHW	2 DHW	3 DHW	1 DHW	1 DHW	1 DHW
Test weight, lbs.†	60.4	59.7	62.6	61.6	61.8	59.8	59.2	62.6	61.9	61.8	61.5
Flour yield, %‡	72.5	70.7	72.7	70.8	71.7	74.2	71.7	75.2	73.1	73.7	71.9
Protein, %	14.5	14.0	13.3	13.0	12.4	14.3	14.1	12.9	12.7	12.7	12.9
Ash, %§	1 46	1.41	1.54	1.42	1.80	1.46	1.37	1.26	1.24	1.16	1.16
Moisture, %	10.5	12.3	10.6	11.8	12.7	10.6	12.5	10.5	12.2	10.6	11.9
Fat acidity**	31.3	38.2	26.2	33.8	25.4	37.5	47.2	31.8	43.7	26.7	40.2
Increase in fat acidity, 1938 to 1943, %		22		29			26		37		50
Analysis of flour:											
Protein, %§	13.8	13.5	12.4	12.4	11.9	13.5	12.8	12.0	11.7	12.5	12.2
Ash, %§	0.34	0.41	0.32	0.40	0.50	0.33	0.42	0.32	0.40	0.32	0.34
Gassing power, mm:											
1st hour	76	76	73	79	78	82	78	86	84	79	81
2d hour	64	94	72	102	126	122	103	94	98	81	95
3d hour	13	17	9	21	92	51	69	17	18	17	19
Total	153	187	154	202	296	255	277	197	200	177	195
Bread:											
Absorption, %	64.0	64.0	64.0	64.0	64.0	64.5	64.5	64.0	64.0	62.0	62.0
Loaf volume, cc:											
Commercial	625	629	670	631	692	675	665	601	553	647	615
Com. + 1 mg bromate	645	663	647	666	772	737	735	644	628	691	692
Com. using 3% yeast	599	640	604	652	750	685	689	604	576	664	640
Average	623	644	640	649	738	692	696	616	585	667	649
Grain and texture:											
Commercial	85G	80G	90VG	80VG	75VG	90VG	80VG	75G	70G	90VG	80VG
Com. + 1 mg bromate	90VG	85G	90VG	85VG	85VG	100VG	85VG	90VG	80G	95VG	90VG
Com. using 3% yeast	85G	95G	85G	85VG	90VG	95VG	90VG	75G	75G	85G	80VG
Color of crumb:											
Commercial	90Cr	85Cr	100Cr	80Cr	80Cr	90Cr	90Cr	85Cr	75Cr	85Cr	85Cr
Com. + 1 mg bromate	95Cr	90Cr	95Cr	90Cr	95Cr	95Cr	95Cr	90Cr	85Cr	90Cr	90Cr
Com. using 3% yeast	86Cr	80Cr	80Cr	85Cr	85Cr	95Cr	85Cr	75Cr	70Cr	80Cr	80Cr
Single figure value:											
Commercial	76.0	75.0	91.0	78.0	89.0	91.0	86.0	67.0	56.0	85.0	76.0
Com. + 1 mg bromate	86.0	84.0	86.0	88.0	109.0	107.0	102.0	85.0	75.0	96.0	94.0
Com. using 3% yeast	70.0	78.0	71.0	84.0	106.0	95.0	94.0	67.0	19.0	83.0	80.0

*Lower commercial grade assigned in 1938 due to the factor damaged wheat. Kernels with weevil eaten germ at that time classified as "damaged".
†Dockage free. ‡Moisture free. §13.5% moisture basis. **Milligrams of KOH per 100-gm sample (dry matter basis).
††Wheat and flour protein content apparently in error in 1938 report.

of the wheat and is expressed in terms of the "fat-acidity value" defined as the number of milligrams of potassium hydroxide required to neutralize the free fatty acids from 100 grams of wheat ascertained on a dry matter basis (5).

Bread-baking tests were made by the straight-dough method, employing the baking formula ingredients most commonly used by commercial bakers. The chemical, milling, and baking tests made in 1943 on these samples were conducted by the same method and in a similar manner to those made in 1938. Any changes occurring in the last 5 years in the properties of the wheats are, therefore, most likely due to storage and not to differences in formulas or methods.

EXPERIMENTAL RESULTS

The milling and baking results obtained in 1943 with the samples grown in previous years are shown in Table 1. Included also are comparable data obtained in the tests made in 1938 in order to facilitate comparison. The thiamine content of the grain, flour, and bread is shown in Table 2 and the germination percentage in Table 3. The latter table includes the germination percentage for each lot 6 months after harvest and at the end of various periods of storage up to 22 years as reported by Robertson, *et al.* (3, 4). Thiamine determinations were made in 1943 for the first time.

The test weights of the grain were slightly but consistently less in 1943 than in 1938. Flour yields also averaged slightly less than in 1938, the only exception being the 1921 crop of Marquis. Ash content of the wheat was substantially the same in 1943 as in 1938, but that of the flour was consistently higher, due perhaps to a more brittle bran coat. This, however, was not apparent from the inspection of the grain or in the handling properties of the wheat in the mill. As noted above, samples were milled in a like manner in both 1938 and 1943. Except for possible differences in ash, it appears that the conditions of storage have not materially altered the milling characteristics of the lots of grain stored up to 22 years.

It will be noted that there are no important differences between the protein content of the lots of the same variety tested in the two different years. The differences that do exist perhaps can be attributed to random errors of sampling and not to the condition of the grain resulting from storage.

Fat acidities determined in 1943 showed increases ranging from 20 to 37% for the Marquis samples and from 26 to 50% for the Kanred samples, as compared with the results of the tests made in 1938. The greatest percentage increase was for the 1926 Marquis and for the 1929 Kanred. None of the fat acidity values for Marquis tested in 1943 was lower than 33.8%, with the highest value recorded for the 1923 sample of 61.2%. The 1942 sample of Marquis had a value of 25.4%, which is about normal or perhaps slightly higher than would be expected in sound normal freshly harvested wheat. The Kanred samples averaged 40.2% or higher in fat acidity. It is generally considered that fat acidity values in excess of about 25 indicate incipient deterioration, but in the present study such deterioration as may have occurred was not reflected in the baking quality of the flour.

Gassing power determinations made on the flour were higher in 1943 than in 1938, but the increase was small compared with the differences between crops.

BAKING TESTS

Three formulas were used in the baking tests. The results indicate that the quality for bread in most cases was substantially the same in 1943 as in 1938. For the 1921 crop of Marquis, the bread produced in 1943 was better than that made in 1938. The difference, however, is no greater than might be expected considering the uncertainty of exactly duplicating the conditions when tests are made so far apart. It is of special interest to note that the 1921 Marquis, which had been stored longer than any other, produced bread superior to that of the 1927 crop with practically the same protein content. It was also better than the 1929 and almost as good as the 1942 crops of Marquis, though for these later crops the protein content also was less. There are no marked differences between the Kanred lots tested in 1943 as compared with those made in 1938.

VITAMIN B_1 (THIAMINE) TESTS

Thiamine determinations have been made of the wheat, flour, and bread. The results are given in Table 2. The thiamine content of Marquis varied from 4.6 micrograms per gram for the 1925 crop to 7.3 micrograms per gram for the 1923 crop. The variation was less for Kanred, but fewer years are represented. The 1921 crop of Marquis was higher than that for other crops, testing 5.7 micrograms per gram, while the 1924 crop of Kanred was the lowest for that variety, testing 5.0 micrograms per gram. The thiamine content of the flour and bread were very similar. Since no determinations of thiamine were made previous to 1943, it is not possible to determine accurately from these data the effect of storage on thiamine content. Considering, however, the known variation in thiamine content of wheat of different crops as shown by other investigators, and the fact that the 1921 and 1923 samples were highest, the data presented

TABLE 2.—*Vitamin B_1 (thiamine) content of wheat, flour, and bread.**

Crop year	Wheat, microgram per gram (as is H_2O basis)	Flour, microgram per gram (as is H_2O basis)	Bread, microgram per gram (air-dried at 60° C)
		Marquis	
1921	6.7	0.8	1.1
1922	5.9	1.1	1.0
1923	7.3	1.4	1.0
1924	5.7	1.0	0.8
1925	4.6	1.0	0.9
1926	5.9	1.2	1.0
1927	6.1	0.6	1.0
1929	6.2	1.2	1.1
1942	6.2	1.2	0.9
		Kanred	
1921	5.7	0.6	0.9
1924	5.0	0.6	0.9
1929	5.5	0.3	0.7

*These data were supplied by K. C. Hammer in letter dated January 29, 1944.

herein suggest that there has been no great loss due to storage under the conditions of this experiment.

GERMINATION TESTS

The results of germination tests made after 6 months' storage and again in 1938 and 1943 are shown in Table 3. All germinated well when the first tests were made, the lowest being 88% for the 1942 crop of Marquis. The tests made in 1938 and in 1943 reveal marked differences, the wheat stored the longest being lowest, as would be expected. By 1943 the Kanred harvested in 1921 tested only 4.0% and the Marquis harvested the same year only 22%. It is of interest to note that even though some of the wheat germinated very poorly, good bread was made from it.

TABLE 3.—*Germination percentage of the wheats for various periods of years after harvest.*

Crop year	Months after harvest	Germination, %	1938 tests		1943 tests	
			Years after harvest	Germination, %	Years after harvest	Germination, %
			Marquis			
1921	6	98.0	17	46.0	22	22.0
1922	6	97.5	16	70.0	21	44.0
1923	6	93.0	15	56.0	20	31.0
1924	6	93.5	14	82.0	19	55.0
1925	6	97.5	13	62.0	18	35.0
1926	6	95.5	12	83.0	17	41.0
1927	6	98.5	11	91.5	16	78.0
1929	6	97.0	9	94.0	14	85.0
1942	6	88.0	—	—	—	—
			Kanred			
1921	6	95.0	17	38.0	22	4.0
1924	6	94.0	14	47.0	19	39.0
1929	6	93.0	9	90.0	14	80.0

SUMMARY

Milling, baking, vitamin B_1 (thiamine), and germination tests have been made of nine samples of Marquis wheat grown for the crop years 1921 to 1927, inclusive, and 1929 and 1942, and of Kanred wheat grown for the crop years 1921, 1924, and 1929. The wheat samples were stored at Fort Collins, Colo., in a dry, unheated room for periods varying from 14 to 22 years.

Twenty-two per cent of Marquis and 4% of Kanred germinated after storage for 22 years.

Storage had no consistent effect on the protein content of the grain.

The ash content of the flour increased somewhat with storage, due perhaps to brittleness of the bran coat, with the result that more of it pulverized in milling and was carried over into the flour.

There was a definite and fairly regular but small increase in fat acidity with storage, those samples stored for the longer periods having fat acidity values which ordinarily would be indicative of considerable deterioration. Such deterioration, however, was not apparent from the bread baking tests, since satisfactory bread was made from all lots of flour.

The best bread was made from the 1921 crop, the small difference as compared with later crops being due, no doubt, to the higher protein content of the flour.

Determinations of thiamine content of the wheat, flour, and bread were made in 1943. The differences were no greater than might reasonably be attributed to differences in the grain when it was first stored.

LITERATURE CITED

1. HAMMER, K. C., STEWART, W. S., and MATRONE, G. Thiamine determination by the fungus-growth method and its comparison with other methods. Food Res., 8:444–452. 1943.
2. ROARK, R. C., and COTTON, R. Z. Tests of various alipathic compounds as fumigants. U. S. D. A. Tech. Bul. 162. 1929.
3. ROBERTSON, D. W., FIFIELD, C. C., and ZELENY, LAWRENCE. Milling, baking, and chemical properties of Colorado-grown Marquis and Kanred wheat stored 9 to 17 years. Jour. Amer. Soc. Agron., 31:851–856. 1939.
4. ————, LUTE, A. M., and KROEGER, H. Germination of 20-year-old wheat, oats, barley, rye, sorghum, and soybeans. Jour. Amer. Soc. Agron., 35:786–795. 1943.
5. ZELENY, LAWRENCE, and COLEMAN, D. A. Acidity in cereals and cereal products, its determination and significance. Cereal Chem., 15:580–595. 1938.

NOTES

RELATION OF CAROTENE AND CRUDE PROTEIN CONTENT OF GRASSES

RELATIONSHIPS between carotene and crude protein content have been noted by various workers.

Studies on grasses may be divided into those in which the grass was cut completely at intervals, as in lawn mowing, and maturity studies where the grass was cut at different stages of growth. In the lawn mower type of sampling, Thomas and Moon[1] reported a correlation coefficient for carotene with crude protein of plus 0.530 for 46 samples. Moon[2] in a further study obtained an r value of plus 0.543 where no fertilization was used, plus 0.233 for nitrate of soda treatment, and plus 0.332 for sulfate of ammonia treatment. Moon[3] also gives an r value of plus 0.89 in a maturity study on mixed herbage. Smith and Wang[4] gave an r value of plus 0.85 for 63 samples of rye grass, white clover, cocksfoot, and timothy.

The correlation coefficient (r) has been computed for buffalo grass, *Buchloe dactyloides*, and blue grama, *Bouteloua gracilis*, using the

[1]THOMAS, B., and MOON, F. E. Emp. Jour. Exp. Agr., 6:235–244. 1938.
[2]MOON, F. E. Jour. Agr. Sci., 29:524–543. 1939.
[3]MOON, F. E. Emp. Jour. Exp. Agr., 7:225–234. 1939.
[4]SMITH, A. M., and WANG, TUNG. Jour. Agr. Sci., 31:370–378. 1941.

data of Langham, McMillen, and Walker.[5] The data used is from Table 1 of their report, using the figures from the first sample taken in a given year to the last sample before a killing frost, inclusive. The following values of r were obtained:

Year	Buffalo grass	Blue grama
1939	0.96	0.96
1940	0.97	0.99
1941	0.89	0.94

The data are shown graphically in Fig. 1, the line being fitted by the method of least squares.

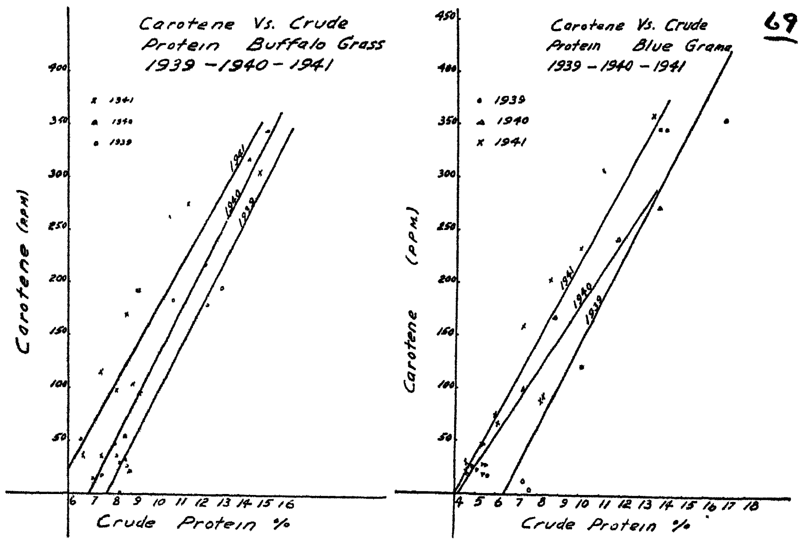

FIG. 1.—Carotene vs. crude protein for buffalo grass and blue grama grass from data of Langham, McMillen, and Walker.

The sources quoted indicate a high relationship between carotene and crude protein in maturity studies of grasses. The relationship becomes less with the lawn mower type of sampling and still less when clipping is combined with nitrogenous fertilization.

Carotene is chemically unstable. It is reasonable to suppose that it is continually being formed and broken down in the plant. The breakdown products may assist in the fixation of nitrogen by providing methyl groups for certain of the amino acids. When nitrogen is being assimilated rapidly as a result of clipping, vigorous growth in the young plant, or nitrogenous fertilization, it is probable that the proposed mechanism is not sufficient to fix the nitrogen and other mechanisms become more important.—LLOYD G. KEIRSTEAD, *Agricultural Experiment Station, Orono, Maine.*

[5]LANGHAM, WRIGHT, MCMILLEN, WARREN N., and WALKER, LAMAR. Jour. Amer. Soc. Agron., 35:35–42. 1943.

A SUGGESTED USE OF A YELLOW-FRUITED TOMATO VARIETY AS A BORDER FOR FERTILIZER OR VARIETY TRIALS OF RED-FRUITED TOMATOES

IN FERTILIZER investigations with tomatoes at the Utah Agricultural Experiment Station there has been considerable difficulty in measuring the response of tomatoes to fertilizer applications made on the soils. Most of the trouble has been in the harvesting. The vines are large and intergrown with one another, making it difficult for the person harvesting to determine exactly which plant the fruits are on, and in which plot they belong. As a result, fruits were often picked from the guard rows and even from other plots, and included in the harvest from a particular plot.

In order to eliminate this source of error, Mingold, a yellow-fruited variety, has been planted on the border rows. Thus, each plot is completely surrounded by yellow-fruited plants. Mingold is similar in its growth habits to the Stone A variety, which has been used in the experiments. At the time of each harvest the picker is instructed to pick all the ripe fruits within the yellow border.

This simple idea has worked very successfully in making each plot a distinct unit. Others have expressed an opinion that it will help them in solving similar problems. It can be used in testing fertilizer response or variety differences.—L. H. POLLARD AND H. B. PETERSON, *Utah Agricultural Experiment Station, Logan, Utah.*

BOOK REVIEWS

A MANUAL OF SOIL FUNGI

By Joseph C. Gilman. Ames, Iowa: The Collegiate Press Inc. 392 pages, illus. 1945. $5.

THE author has pointed out the importance of soil microbiota and that their biological complexities are still in the main obscure. The significance of soil fungi is becoming more and more evident, not only from a standpoint of soil decomposition and fertility, but because they may play an important part in the production of plant and animal diseases and in our everyday life, causing spoilage of foods and materials. The microbiologists and biochemists are continually finding new uses for soil fungi in the production of industrial and medical chemicals. The plant pathologists still have much to learn about soil biological factors in the possible control or regulation of soil pathogens in combating various soil-borne diseases. Undoubtedly, the surface of these subjects has just been scratched and we should look forward towards newer discoveries of fungous products and biological relationships which will aid in the control of plant and human diseases.

The publication of this excellent book is timely and will serve well as a tool for the identification of fungi encountered by the soil microbiologist. The author stated that the volume does not profess to contain much new data, but that it has brought together the

descriptions of the fungi which have been reported as having been isolated from the soil. The fungi included in the book are chiefly those species which have been cultivated artificially on biological media. The terrestrial mushrooms; plant pathogens which are considered to be soil-borne and have not been isolated directly from the soil; forms reported from leaf molds, decayed wood, or other substrates that have not become fully incorporated in the soil complex, have been excluded.

To clarify terms used in the descriptions, a short discussion is given of fungi, sexual spores, and asexual spores. The keys for identification are in general based on this scheme and, therefore, are highly artificial. Existing keys were utilized with modifications to fit the fungi described. For the more general section, they are those of Lindau in Engler and Prantl, "Die naturlichen Pflanzenfamilien." The latest or best monographs of the various groups, however, were utilized whenever possible for the keys to the species.

The body of the manual presents a key to the classes, orders, and families of soil fungi and detailed descriptions of each fungus treated. The descriptions are clear-cut and complete. In certain instances, they are accompanied with text figures. References are given of the countries from which each soil fungus was isolated. A pertinent literature list, glossary, and index are included.

This volume is a real contribution to a much-neglected field. It will save valuable time for all workers in soil microbiology.—OTTO A. REINKING.

STATISTICAL METHODS FOR RESEARCH WORKERS

By R. A. Fisher. Edinburgh and London: Oliver and Boyd. Ed. 9. XV + 350 pages, illus. 1944. 16 shillings.

THE eight editions of this standard work have been reviewed in this JOURNAL, so comparison is made with the eighth edition only (Vol. 34, page 204). All the text of the eighth edition is included in the ninth edition and the number of pages has been increased from 344 to 350. The additional material consists of (1) a square root method and chart for studying frequency ratios provided by different samples that may or may not be homogeneous, added to Section 10.1, 2 pages; (2) a change in the values for the *k* and *g* statistics, Section 14; (3) an additional paragraph explaining the *c* coefficients, Section 29; (4) a paragraph further discussing the correlation coefficient, Section 30. (5) Section 57.3, about 4 pages, "Test of Homogeneity of Evidence used in Estimation", is new. The author states, "The method of this section is available when estimation is based on measurements and not on frequencies so that no alternate value based on frequencies can be calculated." (6) The list of publications by the author includes the period 1942 and 1943.

The numbering of sections, tables, and examples found in the eighth edition have not been changed. The format is the same, but, by the use of thinner paper, the volume is about two-thirds as thick as that of the previous issue. The presswork and binding is of the same high standard found in earlier editions.—F. Z. HARTZELL.

AGRONOMIC AFFAIRS

ABSTRACTS OF 45,000 SEIZED ENEMY-OWNED U. S. PATENTS NOW AVAILABLE

THE publication of two sets of abstracts or short descriptions of 45,000 alien-owned U. S. patents seized by the Alien Property Custodian of the United States Government has just been announced by James E. Markham, the Custodian.

These patents were developed by our enemies at a cost of millions of dollars and involved millions of man hours of work. They contain many items which may be of value in prosecuting the war and also for postwar use. The patents cover practically every field of manufacture. Licenses to most of these patents are available to American citizens at a nominal fee of $15 per patent and are good for the life of the patent.

To help find items of particular interest, the ABSTRACTS have been classified and indexed. The MECHANICAL AND ELECTRICAL ABSTRACTS (about 37,000 patents) consist of a short description and an illustrative drawing. The CHEMICAL ABSTRACTS (about 8,000 patents) consist of a condensed description of the chemical principle involved.

The set of the MECHANICAL AND ELECTRICAL ABSTRACTS is bound in four volumes comprising approximately 4,000 pages and includes a 48-page index. The set of CHEMICAL ABSTRACTS in 33 sections, contains about 2,000 pages and has a 400-page index. Each set of abstracts sells for $25 and may be obtained from the Office of Alien Property Custodian, 311 Field Building, Chicago 3, Ill.

If the complete sets of abstracts are not desired, portions of them (sections or classes dealing with any one subject) are obtainable at proportional cost. An index showing the section or class titles and prices may be obtained free of charge by writing to the Alien Property Custodian, 311 Field Building, Chicago 3, Ill.

NEWS ITEMS

LT. COL. M. F. MORGAN, formerly agronomist at the Connecticut Agricultural Experiment Station at New Haven, was killed in action on Leyte on January 15th. Doctor Morgan had long been prominent in the affairs of the Society and was well known for his work in developing quick chemical tests for plant nutrients. He served on the fertilizer committees of the Society and was a former secretary of Section O of the American Association for the Advancement of Science.

—A—

HAROLD R. SMALLEY, Director of the Soil Improvement Work of the National Fertilizer Association, died in Washington, D. C., on February 27th, following a four weeks' illness. A Fellow of the Society, Mr. Smalley was widely known among the agronomists of the country and took a prominent part in the organization and meetings of the National Joint Committee on Nitrogen Utilization, the National Joint Committee on Fertilizer Application, and the Fertilizer Committee of the American Society of Agronomy.

GEORGE H. SERVISS, Extension Associate Professor in Agronomy at Cornell University, has accepted a position as Director of the Soil Building Service of the G. L. F. Cooperative, effective March 1.

—A—

THE INTERNATIONAL MINERALS AND CHEMICAL CORPORATION is adding a $125,000 acidulating plant to its Chicago Heights, Ill., fertilizer factory for the manufacture of superphosphate. The new unit is expected to come into production about March 15 and will increase the capacity of the Chicago Heights plant 25 to 30% over present tonnage.

—A—

THE RETIREMENT on April 1 of Charles J. Brand, Executive Secretary of the National Fertilizer Association, has been announced.

—A—

DR. R. P. BARTHOLOMEW, head of the Department of Agronomy of the Arkansas College of Agriculture, has been named Associate Director of the Arkansas Agricultural Experiment Station. He will continue to serve as head of the Agronomy Department.

—A—

STANLEY F. MORSE, agricultural consultant since 1916 with private practice in the United States, Latin America, and Europe, and previously State Director of Agricultural Extension and Professor of Agriculture at the University of Arizona, has been named chief of the American Food Mission, U. S. Foreign Economic Administration, to French North Africa. Mr. Morse also has been serving as chief of the Food Division of the North African Joint (Anglo-American) Economic Mission. His address is Box 861, Winter Park, Fla.

—A—

DOCTOR E. C. AUCHTER, Administrator of Agricultural Research in the U. S. Dept. of Agriculture since 1941, resigned early in February to accept the position of Director of the Pineapple Research Institute of Hawaii, with headquarters in Honolulu. Doctor P. V. Cardon, who has been assisting Doctor Auchter since the organization of the Agricultural Research Administration in the Department, has been named to succeed Doctor Auchter as Administrator.

—A—

DOCTOR J. J. SKINNER, Senior Biochemist of the Bureau of Plant Industry, Soils, and Agricultural Engineering of the U. S. Dept. of Agriculture since 1935, has retired after 41 years of government service.

—A—

ACCORDING TO *Science*, Doctor Richard E. Schultes, research fellow at the Botanical Museum of Harvard University, is serving as agronomist for the rubber program of the Bureau of Plant Industry, U. S. Dept. of Agriculture, and has spent three and a half years in the Amazonian regions of Colombia. He can be addressed in care of the American Embassy, Bogota, Colombia, S. A.

JOURNAL
OF THE
American Society of Agronomy

VOL. 37 | APRIL, 1945 | No. 4

EFFECT OF PLANTING RATE ON FIBER YIELD OF *URENA LOBATA* L. AS COMPARED WITH KENAF, *HIBISCUS CANNABINUS* L.[1]

JULIAN C. CRANE AND JULIÁN B. ACUNA[2]

Urena lobata L., a plant which is widely distributed in the tropics and sub-tropics, has aroused much interest from time to time for many years in regard to its being utilized as a source of soft fiber suitable for uses in which jute fiber is employed. This plant belongs to the Mallow family (Malvaceàe) and it produces a bast fiber which is light in color, soft, silky, and very flexible. The fiber has been utilized for coarse bagging and cloth materials and has been produced in comparatively small amounts in Madagascar, Belgian Congo, Brazil, and other South and Central American countries. *Urena lobata* in Cuba is called malva blanca, meaning white mallow; while in a localized area of Santa Clara Province it is called Guizazo. In Florida the plant is commonly known as ceasar weed, and is termed by some people French cockle burr.

In December, 1942, a contract was signed by a representative of the Defense Supplies Corporation and the Hershey Corporation for the experimental planting of approximately 5 acres of malva blanca at one of the latter's sugar centrals. During the first part of August, 1943, when the plantings were approximately 2½ months old, the experiment appeared to be a failure due to irregular seed germination and plant growth; but the field was left undisturbed. In September, however, the plantings were inspected and they presented an entirely different appearance in that plant height was more uniform and seed in all parts of the field had germinated. By December, the plants had attained an average height of 5 feet. When the plots were ready for harvesting, facilities for large-scale retting were not available, but small areas of plants were cut from each of the various plots

[1]Joint contribution from the Office of Foreign Agricultural Relations, U. S. Dept. of Agriculture, and the Cuban Agricultural Experiment Station. The collaborative investigations reported here were made possible by funds provided through the United States Inter-Departmental Committee for cooperation with the American Republics, together with the financial support of the Government of Cuba. Received for publication September 14, 1944.

[2]Associate Agronomist, Office of Foreign Agricultural Relations, U. S. Dept. of Agriculture, and Head, Department of Botany, Cuban Agricultural Experiment Station, respectively.

for the purpose of determining the yield of fiber that could be expected as well as the effect of planting rate on yield. This report presents the results obtained.

EXPERIMENTAL METHODS

This experiment was conducted at Central Rosario near Aguacate, Cuba, on a very fertile Matanzas clay soil having a pH of 7.0. The land previously had been in sugar cane, and waste containing lime from the sugar mill had been applied over a period of years.

During the month of March, 1943, the cane crop was cut, and the months of April and May were spent in preparing the land for the malva blanca plantings. This preparation consisted of plowing to a depth of 10 inches with a tractor and a five-disc plow and then of cross-plowing with the same equipment. A second-cross-plowing was done with oxen followed by grading with the use of mules, all of which resulted in an excellent preparation of the seedbed.

The field was divided into six plots, five of which contained 5 cordeles each (approximately ½ acre), while the sixth covered an area of 25 cordeles. The plots were planted by hand on May 28, using unscarified seed that was not free of burrs or carpel parts and which averaged approximately 25,000 seeds per pound. The following planting methods and planting rates were employed:

25 cordeles planted in 8-inch rows with 6 inches between plants in the row (approximately 25 pounds per acre)
5 cordeles broadcasted at the rate of 40 pounds per acre
5 cordeles broadcasted at the rate of 35 pounds per acre
5 cordeles broadcasted at the rate of 30 pounds per acre
5 cordeles broadcasted at the rate of 25 pounds per acre
5 cordeles broadcasted at the rate of 20 pounds per acre

The land was reasonably free of weeds and at no time did they offer competition for the plants. Upon the completion of the experiment, the determination was made that approximately 55 inches of rain had fallen during the 7 months growth period, which was entirely adequate for the growth of this plant.

On January 7, 1944, when the plants were in bloom, three representative square yard samples were cut with a machete from each of the six plots. In cutting the plants, an endeavor was made to select the average as well as the minimum and maximum number of plants per square yard for each of the six treatments. After the plants were cut, they were tied in bundles and the top foot with leaves and small branches was removed. The samples were taken to the Cuban Agricultural Experiment Station where all remaining leaves were removed and the green weight of the stems was determined. After the stems had retted for several days, the fiber was stripped by hand, washed, and dried in the sun.

RESULTS

TABLE 1.—*Plant population, height, and average weight of Urena lobata plants when harvested 7 months after planting.*

Planting rate	Number of plants per sq. yard	Number of plants per acre	Height of plants, feet	Average weight per plant, grams
8 in. × 6 in.	27.0	130,680	8.3	129.8
40 lbs. per acre	26.3	127,292	7.1	153.7
35 lbs. per acre	30.0	145,200	7.6	104.1
30 lbs. per acre	29.3	141,812	7.0	86.8
25 lbs. per acre	25.3	122,452	7.1	82.1
20 lbs. per acre	24.0	116,160	7.0	113.2

Table 1 indicates that although the plots were seeded at different rates, little variation resulted in the ultimate plant stand between treatments. Although the 40-pound treatment was seeded at twice the rate as the 20-pound treatment, the average number of plants per square yard was 26.3 and 24, respectively; while both the 30- and 35-pound treatments had a higher average stand of plants than did the 40-pound treatment.

Considering the number of seeds per pound and the resulting number of plants per square yard which should have developed in each of the different planting rates, an average of only 17% of the seeds planted produced mature plants. For example, seeding at the rate of 30 pounds per acre should have resulted in approximately 157 plants per square yard, but in this treatment only 29.3 plants or 18.6% of the theoretical plant population reached maturity. The only treatment in which the theoretical plant population equaled the actual plant stand obtained was in the plot planted 8 inches between rows and 6 inches between plants. Planting at this distance should have consumed between 5 and 6 pounds of seed with carpel parts per acre. However, as *Urena lobata* seed is very small and seeding by hand to the exact distance and number of plants per hill was exceedingly difficult, approximately 25 pounds of seed per acre were sown. In spite of this excessive seeding rate, the plant stand at harvest time was 27 plants per square yard or exactly the theoretical number if only one seed had been dropped every 6 inches in rows 8 inches apart. Regardless of the difference in rate of seeding between the various plots, the plant population at harvest time was not greatly different among the various treatments. This phenomenon can be attributed to two factors. Although the percentage germination of this seed was not determined before planting, it was clearly evident that a considerable amount did not germinate. More important, however, is the fact that in all the plots at harvest time a number of dead plants of apparently all ages were observed. All evidence points to the fact that under the environmental conditions of this investigation, 30 plants per square yard was the maximum plant population which this particular soil type could support. In other words, regardless of seeding rate, self thinning of the plants due to competition resulted so that an average of 27 plants per square yard was obtained.

The data in Table 1 also show there was considerable variation in the average weight per plant. This was due primarily to non-uniformity of seed germination. As previously pointed out, when the plantings were 2½ months old, germination of the seed had been very slow and irregular, and in many places in the field there were bare spots where no seed had germinated. During the first part of September, however, the remaining seeds in the ground gave evidence of having germinated; and the plots presented a favorable appearance, although the plants were not uniform in height and those which had started growing had branched considerably. The result was that there were some plants with thick stems and large branches, while other plants which germinated late were thin-stemmed and unbranched.

By harvest time the plants had attained a rather uniform height (Table 1) with an average stem diameter of about ½ inch, and upon

close observation little difference could be detected in plant stand among the treatments. Although care was exercised in selecting the samples of plants, considerable error was introduced as a result of the limited samples used.

Yield data in Table 2 show that the yield of fiber per plant was not greatly different between treatments. This indicates that in no treatment did the ultimate stand of plants approach the point where competition between plants was great enough to decrease the rate of growth and the production of fiber.

TABLE 2.—*Yield and percentage fiber of the green weight of Urena lobata stems grown at different planting rates, Aguacate, Cuba, 1943.*

Planting rate	Fiber per plant, grams	Per cent fiber of the green weight of stems	Yield of fiber per sq. yard, grams	Fiber yield per acre, lbs.
8 × 6 in.........	7.1	5.5	196.0	2,089
40 lbs. per acre...	9.2	6.0	186.0	1,982
35 lbs. per acre...	6.0	5.8	179.0	1,908
30 lbs. per acre...	5.5	6.3	161.3	1,719
25 lbs. per acre...	4.5	5.5	116.3	1,239
20 lbs. per acre...	6.5	5.7	136.6	1,456
Average...	6.4	5.8	162.5	1,732

The yield of fiber per acre, based on the average yield of fiber per square yard, had a tendency to decrease with a decrease in planting rate. The data presented in Table 2, however, leave some doubt as to whether significant differences exist in yield of fiber among the various treatments. From the standpoint of uniformity of plant growth, however, which is highly desirable in fiber production, the recommendation is that this plant be planted in rows rather than broadcast.

The percentage fiber of the green weight of the stems was practically the same for all treatments with an average of 5.8. Here again, little difference in plant population among treatments was evident for the percentage of fiber has been shown by research workers, working with other fiber plants, to be higher in thin-stemmed, densely growing plants than in thick-stemmed, sparcely growing ones.

As a basis for comparing fiber yields from malva blanca and kenaf, *Hibiscus cannabinus*, yield data obtained from plantings of the latter plant grown at Central Rosario during the same season and, therefore, under identical soil and climatic conditions, are presented in Table 3. The kenaf planting was located next to the malva blanca plots on the same type of soil and identical seedbed preparation was given both plantings. During the last week of May, 1943, 40 cordeles (about 4 acres) of kenaf were planted in 8-inch rows with 6 inches between plants. When the plants were 80 days old and 11 feet tall, 5 cordeles were cut, and the fiber was extracted by hand after the stalks had retted for several days. The same procedure was followed every 10 days thereafter up to and including 120-day-old plants, when the plants were in blossom.

Data in Table 3 show that with an increase in age of kenaf plants there was a progressive increase in the yield of fiber until, at the 120-day stage over 3,000 pounds of dried fiber were produced per acre. The fiber in the stalks averaged 6.3%, but this was based on the weight of the plants after they had been cut and dried in the field for 3 days before retting. Other investigations conducted on the kenaf plant in Cuba have shown that the fiber content of the green stalks is 5.5% at the time of blossoming and is, therefore, very similar to the percentage of fiber in malva blanca stems.

TABLE 3.—*Yields of fiber obtained from 5 cordeles (approximately ½ acre) of different aged kenaf plants, Hibiscus cannabinus, grown at Aguacate, Cuba, 1943.*

Age of plants when cut, days	Time of retting, days	Stalks retted, lbs.	Dried fiber obtained, lbs.	Fiber, %	Fiber yield, per acre, lbs.
80	7	14,040	720	5.1	1,505
90	8	13,390	850	6.3	1,768
100	10	16,050	1,075	6.6	2,175
110	11	14,575	1,095	7.5	2,237
120	12	24,700	1,500	6.1	3,032
Average	9.6	16,551	1,048	6.3	2,141

DISCUSSION

Urena lobata, when grown on fertile soils and with accompanying climatic conditions which promote good growth, is capable of producing favorable yields of fiber. However, experience with this plant has demonstrated that careful consideration must be given the various cultural factors involved for its successful production.

Perhaps, from an economic standpoint, the soil requirements of this plant will restrict its production to localized areas where the soil is exceptionally fertile. This experiment was conducted on one of the most fertile soils in Cuba and the yield of fiber per unit of land should not be interpreted as being representative of yields to be expected on other soil types or in other locations. This planting was, by far, the best in regard to growth and stand of plants of any ever seen by the authors and was the exception rather than the rule. Experimental row and broadcast plantings made during the summer of 1942 by the Cuban Ministry of Agriculture in Pinar del Rio Province on a sandy loam soil yielded fiber at the rate of less than 1,000 pounds per acre and the tallest plants were less than 6 feet in height. All evidence points to the fact that *Urena lobata* should be planted only on fertile soils similar to the Matanzas clay. Lack of this knowledge by experimenters has undoubtedly been the primary reason for many failures with this crop in the past where it has been grown on unproductive or unadapted soils.

It seems probable that there is a maximum or optimum number of plants that a given soil under certain conditions can support per unit of area; and until this has been determined for all soil types, a

general recommendation for the best seeding rate cannot be made. However, on such soils as the Matanzas clay, it appears wasteful to plant at a rate heavier than 5 to 6 pounds of seed per acre which results in approximately 30 plants per square yard. These figures are based on unscarified seed not free of carpel parts and assumes that germination is 100%. This investigation, however, shows the resulting difficulties when uncleaned and unscarified seed is used. Germination is very irregular and takes place over a period of 2 or 3 months with the result that the planting is composed of plants of different sizes and of different ages. It is recommended, therefore, that before planting *Urena lobata* seed be scarified either with a mechanical seed scarifier or by the use of concentrated sulfuric acid. Excellent results have been obtained with both methods by workers in the United States. Between 4 and 5 pounds of scarified seed to the acre is adequate to give approximately 30 plants to the square yard of land.

Considering the relative advantages and disadvantages of *Urena lobata* vs. kenaf, the authors are of the opinion that the latter, for several reasons, is better adapted than the former to production under Cuban conditions. Kenaf has been grown on various soils at different locations in Cuba and the plants appeared to do equally well. The seed of this plant germinates in about 72 hours and scarification is unnecessary. Although rapidity of growth might not be an important factor in certain seasonal crop programs, nevertheless, in others, the much shorter growing season required by kenaf might work to advantage.

Another outstanding factor which favors the production of kenaf rather than *Urena lobata* in Cuba is the adaptability of the former to mechanical decortication in henequen decorticators. On the other hand, the woody condition of *Urena lobata* stems at harvest time necessitates their being defibered by the slow and costly process of retting. Although to date it has not been definitely determined by manufacturers that decorticated, undegummed kenaf fiber is satisfactory in all respects, nevertheless, this type of fiber has been processed successfully in Cuba on jute spinning equipment and on hard fiber (henequen) rope machinery.

CHEMICAL COMPOSITION OF SIXTY-FOUR SPECIES OF RANGE PASTURE GRASS GROWN ON A VICTORIA CLAY LOAM SOIL[1]

G. S. Fraps and J. F. Fudge[2]

DIFFERENT species of grass grown on the same soil may differ significantly in chemical composition (1, 3, 6).[3] Appreciable differences in chemical composition are of practical importance, since they determine to a considerable degree the feeding qualities of the forage. They are of especial importance in the consideration of species of grass for the reseeding or improvement of depleted ranges. A given species may be a good one because of type of growth, ease of establishment or maintenance under range conditions, or palatability, but a poor species on account of chemical composition. For example, angleton grass, *Andropogon annulatus*, possesses some highly desirable characteristics (5) but is sometimes low in protein and phosphoric acid as compared with other species (7). A study of the comparative chemical composition of different species of grasses grown on the same soil was therefore considered desirable. Under ordinary range conditions, such a study is limited by the comparatively few species found on a given area. An opportunity to study the chemical composition of a large number of species grown on the same soil and under uniform conditions was afforded by nursery plantings made near San Antonio, Texas, by the Nursery Division of the Soil Conservation Service, U. S. Dept. of Agriculture.

MATERIAL AND METHODS

In establishing the nursery, pure plantings of the different species were made either from seeds or by vegetative propagation. Many of the most important species found on Texas ranges were included, as well as some species which do not occur on Texas ranges but which seemed to offer promise for introduction. Plantings were made in rows on a uniform, level area of Victoria clay loam. A sample of the soil (0 to 6 inches in depth) was found to contain 0.108% total nitrogen, 0.078% total phosphoric acid, 50 p.p.m. of phosphoric acid soluble in 0.2 N nitric acid, and had a pH of 8.01 and a capacity to neutralize acid equivalent to 13.15% calcium carbonate. The soil was calcareous, fair in total nitrogen, and deficient in active phosphoric acid. The plants of all species were well established and growing vigorously when sampling was begun. Samples numbering 336 were collected in June, August, and October of 1937 and in February, April, and June of 1938. Samples of a few species which are of importance only in the early spring were collected only in February and April, 1938.

The samples taken represented the entire growth up to the date of collection. They were packed loosely in cheesecloth bags, dried at about 45° C, and ground in a Wiley mill. Protein, phosphoric acid, and lime were determined in all samples. Crude fiber, nitrogen-free extract, fat, ash, and water were determined in samples collected in June, August, and October, 1937, and in February, 1938.

[1]Contribution from the Division of Chemistry, Texas Agricultural Experiment Station, College Station, Tex. Received for publication November 3, 1944.

[2]Chief, Division of Chemistry, and Chemist, respectively. The writers gratefully acknowledge the cooperation of C. B. Webster, Chief Nurseryman, Soil Conservation Service, U. S. Dept. of Agriculture, and his coworkers in securing the samples, and of T. L. Ogier, W. Walker, and others in the Division of Chemistry for assistance in the analytical work.

[3]Figures in parenthesis refer to "Literature Cited", p. 257.

EXPERIMENTAL RESULTS

The botanical and common names of the species sampled, their classification as to habit of growth, whether tall or short, and usual habitat, whether from the humid or subhumid section of the state, and averages for various chemical constituents are shown in Table 1. Protein and phosphoric acid are the principal limiting factors in range animal production and the percentages of these constituents are known to decrease with advancing maturity. For these reasons, unweighted average analyses were calculated for protein and phosphoric acid in samples representing young (early vegetative stage), intermediate (late vegetative and bloom stages), and mature growth. All of the samples collected in April, most of those collected in June. 1937, and a few of those collected in February were of young growth, Nearly all samples collected in August and in June, 1938, were of intermediate growth. Nearly all samples collected the last of October and most of those collected in February were of mature growth. Averages given. for lime, crude fiber, and nitrogen-free extract were calculated from analyses for all samples of each species. Crude fiber and nitrogen-free extract were not determined in samples collected in April and June, 1938. Averages for water, fat, and ash are not given in Table 1 because they are of minor importance. Water in nearly all dried samples ranged from 6 to 8%. Analyses given in Table 1 are for the samples as dried. The data were also averaged for groups of species according to their habit of growth or usual habitat. Detailed discussion of the data is precluded because of the limitations of space.

PROTEIN

Protein in the young grasses ranged from 18.2% in *Panicum antidotale* to 7.1% in *Muhlenbergia utilis*. *Cynodon dactylon* and *Panicum antidotale* contained more than 15% protein, 22 other species contained from 10.5 to 15.0%, and 38 species contained from 7.1 to 15%. Protein averaged relatively high in *Cynodon*, *Chloris*, and *Paspalum* species and low in *Hilaria* and *Muhlenbergia* species. Protein was relatively high in samples of *Agropyron Smithii*, *Agropyron cristatum*, *and Bromus catharticus* collected only in February and April. These grasses are grazed only in early spring.

Protein decreased rapidly in most species as they passed from young to intermediate to mature stages of growth. At intermediate stages of growth, 14 species contained less than 6% protein, and hence were deficient in protein for range beef animals (3). In the mature growth, protein ranged from 11.3% in *Panicum antidotale* to 2.7% in *Sporobolus asper Hookeri*. Nineteen species contained from 6.0 to 10.5% and 39 species contained less than 6.0% protein. The relative effect of maturity upon the protein content varied widely with different species. When young, Bermuda grass was much higher then buffalo grass (15.7 vs. 8.7%) but was slightly lower when mature (5.8 vs. 6.4%). Young growth of *Eragrostis curvula* and *E. Lehmanniana* contained about the same percentage of protein (10.3% vs. 9.5%), but when mature, *E. Lehmanniana* was much higher than *E. curvula* (6.6% vs. 4.3%). Protein in grasses common to the humid

section of the state averaged higher than those from the subhumid section when young and lower at intermediate and mature stages of growth. Protein in short grasses averaged higher than in tall grasses throughout the year.

PHOSPHORIC ACID

Phosphoric acid in the young growth ranged from 0.69% in *Cynodon dactylon* to 0.32% in *Stipa leucotricha*, and in mature grasses from 0.44% in *Paspalum distichum* to 0.14% in *Hilaria Jamesii*. Phosphoric acid averaged highest in *Cynodon* and *Paspalum* species and lowest in *Andropogdon* and *Hilaria* species. *Stipa leucotricha* (0.32%) was the only grass which contained less than 0.33% phosphoric acid, and hence could be considered as slightly deficient in phosphoric acid, while the others were not deficient. When mature, all of the species, except *Paspalum distichum*, *P. Hartwegianum*, *P. notatum*, *P. virgatum*, and *Cynodon dactylon*, were deficient in phosphoric acid, although several species were only slightly deficient. Phosphoric acid was considerably higher in short grasses than in tall grasses at all stages of growth, and the relative decrease due to maturity was smaller in the short grasses.

RELATION BETWEEN PROTEIN AND PHOSPHORIC ACID

In general, protein and phosphoric acid were closely related, but there are many exceptions. A relatively high protein content was not necessarily an indication of a correspondingly high phosphoric acid content. Mature *Paspalum lentiferum* was much higher than *P. vaginatum* in protein (5.9 vs. 4.5%), but only about half as high in phosphoric acid (0.20% vs 0.35%). *Panicum antidotale* contained practically the same percentage of phosphoric acid but twice the percentage of protein as *Paspalum vaginatum*. *Eragrostis curvula* was considerably higher than *E. Lehmanniana* in protein but only half as high in phosphoric acid.

Advancing maturity or dry weather had a greater or earlier effect upon the protein than upon the phosphoric acid. Protein and phosphoric acid in all samples collected on June 30, 1937, averaged 8.9% and 0.40%, respectively. Corresponding averages for samples on August 12, 1937, were 6.9% and 0.34%. Advancing maturity had reduced both protein and phosphoric acid, but the relative reduction in protein was considerably greater than in phosphoric acid. Protein and phosphoric acid in samples collected in June, 1938, averaged 7.0% and 0.41%, respectively. Samples collected in June, 1937, after a favorable period of growth, were much higher in protein than those collected in June, 1938, after a long, dry period, but the unfavorable growing conditions during 1938 had no effect upon the average phosphoric acid.

When both protein and phosphoric acid are considered, several of the species were particularly outstanding. *Cynodon dactylon*, *Paspalum distichum*, and *P. Hartwegianum* were relatively high in protein and phosphoric acid throughout their growth. *Chloria eucullata*, *Cynodon plectostachvum*, *Paspalum notatum*, and *Sataria macrostachya*

TABLE 1.—*Average chemical composition of different species of grasses grown on a Victoria clay loam.*

Botanical and common name and classification*	Protein			Phosphoric acid			Lime, %	Crude fiber, %	Nitrogen-free extract, %
	Young growth, %	Intermediate growth, %	Mature growth, %	Young growth, %	Intermediate growth, %	Mature growth, %			
Agropyron cristatum† I	20.5	—	—	0.70	—	—	1.38	23.5	32.2
Agropyron Smithii, bluestem† TB	16.4	—	—	0.51	—	—	0.68	25.6	36.6
Andropogon Hallii, turkeyfoot TB	9.3	6.3	3.8	0.45	0.40	0.18	0.60	32.0	46.5
Andropogon littoralis, seashore beard TH	9.0	5.9	4.5	0.38	0.32	0.27	0.73	31.3	46.8
Andropogon perforatus TB	10.4	6.7	4.6	0.49	0.39	0.21	0.77	32.5	41.8
Andropogon provincialis, big blue stem TH	9.9	6.1	5.0	0.46	0.34	0.16	0.72	28.3	46.9
Andropogon saccharoides, silver beard TB	9.7	4.7	3.7	0.45	0.25	0.16	0.69	31.4	45.2
Andropogon scoparius, little bluestem TH	9.0	5.5	4.0	0.37	0.29	0.18	0.75	30.3	47.2
Bouteloua curtipendula, sideoats grama TB	9.3	6.2	5.3	0.41	0.27	0.16	0.65	32.5	40.4
Bouteloua eriopoda, black grama SB	9.0	6.7	6.3	0.48	0.40	0.26	0.72	30.6	44.0
Bouteloua filiformis, slender grama SB	10.9	7.7	7.0	0.64	0.41	0.24	1.09	25.9	44.2
Bouteloua gracilis, blue grama SB	11.2	7.6	6.0	0.50	0.36	0.28	1.15	26.4	42.7
Bouteloua hirsuta, hairy grama TB	9.6	7.1	6.1	0.45	0.43	0.24	1.13	26.6	43.6
Bouteloua rigidiseta, Texas grama SB	9.0	7.9	6.5	0.48	0.35	0.27	1.47	23.9	38.1
Bromus catharticus, rescue† SH	16.0	—	—	0.63	—	—	0.91	17.0	32.8
Buchloe dactyloides, buffalo SB	8.7	7.1	6.4	0.50	0.41	0.32	1.12	23.9	45.7
Chloris ciliata SB	8.9	6.7	4.6	0.49	0.40	0.28	0.89	30.6	46.3
Chloris cucullata, blackfinger SB	12.8	8.8	6.2	0.47	0.35	0.23	1.07	28.2	38.6
Chloris gayana, Rhodes TB	11.3	7.6	5.3	0.41	0.32	0.23	1.03	30.5	40.6
Chloris petrea TB	8.6	6.7	5.1	0.50	0.38	0.19	0.75	30.4	44.1
Cynodon dactylon, Bermuda SH	15.7	7.1	5.8	0.69	0.40	0.35	1.87	21.9	44.7
Cynodon dactylon, giant Bermuda SH	9.7	7.5	6.1	0.61	0.48	0.27	0.84	24.9	46.1
Cynodon dactylon, St. Lucy I	9.8	5.6	5.0	0.49	0.38	0.30	1.13	23.3	50.1
Cynodon plectostachyum I	10.2	8.9	8.1	0.66	0.48	0.27	1.33	28.5	44.1
Elymus canadensis, wild rye† TB	12.3	—	—	0.52	—	—	0.63	23.1	37.7
Eragrostis curvula, weeping love I	10.3	6.7	4.3	0.38	0.24	0.17	0.86	30.8	46.1
Eragrostis Lehmanniana I	9.5	7.2	6.6	0.53	0.44	0.30	0.87	32.1	41.7
Eragrostis secundiflora SH	10.5	5.9	5.2	0.40	0.37	0.22	0.85	31.6	45.2
Hilaria Belangeri, curly mesquite SB	7.5	6.0	5.1	0.44	0.37	0.27	1.00	25.9	43.0
Hilaria Jamesii, Galleta TB	9.2	7.2	4.3	0.41	0.38	0.14	0.58	31.5	42.2

Hilaria mutica, Tobosa TB	10.3	7.7	6.0	0.39	0.30	0.18	0.69	30.5	42.5
Hyparrhenia hirta, South African bluestem I	11.7	6.8	3.8	0.36	0.32	0.18	0.68	31.0	40.4
Muhlenbergia arenacea TB	9.3	5.7	5.6	0.48	0.38	0.27	0.84	29.9	44.8
Muhlenbergia repens, creeping muhly SB	7.9	6.4	5.2	0.50	0.34	0.21	0.82	28.2	48.2
Muhlenbergia utilis SB	7.1	5.4	4.9	0.43	0.35	0.21	0.88	27.9	48.8
Panicum antidotale, stick I	18.2	12.5	11.3	0.54	0.33	0.27	0.68	29.4	39.0
Panicum Hallii TB	9.2	5.9	5.1	0.39	0.25	0.19	26.9	26.9	43.2
Panicum obtusum, vine mesquite TB	11.3	6.6	4.3	0.51	0.48	0.17	0.81	31.2	43.0
Panicum texanum, Texas millet TH	9.6	—	5.5	0.38	—	0.16	1.10	28.0	44.1
Panicum virgatum, switch TH	10.3	8.3	—	0.46	0.32	—	0.66	30.5	43.3
Pappophorum bicolor TB	9.2	7.8	5.0	0.43	0.32	0.15	0.50	34.7	40.9
Paspalum dilatatum, Dallis SH	9.5	6.4	5.0	0.47	0.45	0.24	0.82	32.4	43.7
Paspalum distichum, Knot SH	11.0	—	4.9	0.61	—	0.44	0.87	22.1	51.8
Paspalum floridanum TH	11.8	6.9	4.6	0.51	0.39	0.22	1.10	30.3	43.0
Paspalum Hartwegianum SH	11.1	6.2	4.7	0.59	0.47	0.34	0.90	29.8	44.1
Paspalum lentiferum SH	12.7	7.4	5.9	0.45	0.28	0.20	1.35	32.2	40.0
Paspalum lividum, longtom TH	10.9	4.8	4.3	0.53	0.34	0.24	0.69	28.7	49.3
Paspalum notatum, Bahia SH	10.1	6.4	4.1	0.61	0.50	0.33	1.13	28.8	43.7
Paspalum pubiflorum SH	10.9	6.4	5.9	0.43	0.35	0.26	0.95	27.8	44.6
Paspalum Urvillei, Vasey TH	11.4	7.7	5.2	0.61	0.36	0.29	0.99	31.9	41.4
Paspalum vaginatum SH	9.1	5.9	4.5	0.58	0.49	0.35	0.86	24.0	49.9
Poa arachnifera, Texas bluegrass† SH	8.9	—	—	0.37	—	—	0.94	28.4	38.7
Setaria macrostachya, plains bristlegrass TB	12.6	9.7	9.2	0.67	0.36	0.29	0.93	30.8	38.4
Sorghastrum nutans, Indian TH	10.7	5.8	4.4	0.48	0.38	0.27	0.90	28.8	44.5
Sporobolus airoides, alkali sacaton TB	11.2	9.0	6.9	0.41	0.39	0.30	1.12	27.8	41.1
Sporobolus asper Hookeri TH	7.9	4.6	2.7	0.49	0.40	0.20	0.66	27.8	43.0
Sporobolus Poiretii, smut grass TH	9.6	5.7	5.2	0.41	0.29	0.20	0.84	31.9	45.2
Sporobolus virginicus, seashore rush TH	9.2	6.3	4.7	0.48	0.39	0.29	1.02	27.1	45.5
Stipa leucotricha, Texas needle TB	11.9	9.3	8.0	0.32	0.24	0.18	1.05	24.7	37.3
Trachypogon montufari, crinkle awn TH	8.4	5.3	4.1	0.44	0.31	0.18	0.66	31.3	46.7
Trichloris pluriflora TB	10.7	8.0	6.4	0.42	0.34	0.16	0.54	32.1	41.8
Triodia mutica, slim triodia TB	12.8	7.6	6.9	0.47	0.37	0.25	1.04	31.0	41.3
Triodia texana, Texas triodia TB	11.5	10.2	7.1	0.47	0.36	0.21	0.71	31.6	38.4
Tripsacum dactyloides, eastern gama TH	9.1	6.2	3.4	0.50	0.31	0.19	0.60	28.1	48.7
Averages For Different Groups of Species									
Short grass, humid section (SH)	11.0	6.5	5.3	0.54	0.42	0.30	1.08	26.2	45.9
Tall grass, humid section (TH)	9.8	6.3	4.6	0.46	0.33	0.21	0.80	29.6	45.4
Short grass, subhumid section (SB)	9.3	7.0	5.6	0.49	0.37	0.26	1.02	27.1	44.0
Tall grass, subhumid section (TB)	10.3	7.4	5.8	0.44	0.34	0.21	0.81	30.5	41.9

*S = Short; T = Tall; H = Humid section; B = Subhumid section; I = Introduction.
†Samples collected only in February and April and not included in averages. These grasses are grazed only in the early spring.

were high in protein and phosphoric acid when young but not when older. A sample of *Agropyron cristatum* collected in April 29 contained 23.0% protein and 0.81% phosphoric acid, the highest in any sample analyzed. While a few species were superior, most of the species were relatively uniform.

OTHER CONSTITUENTS

Lime was relatively high in all species, but *Cynodon*, *Paspalum*, *Chloris*, and *Bouteloua* species were considerably higher, and *Andropogon* and *Hilaria* species lower than most of the other species. Lime in most species was not greatly affected by advancing maturity. In some species, lime was highest during early growth and in others during late growth. Lime was much lower in tall grasses than in short grasses. Crude fiber averaged less than 24% in *Cynodon dactylon*, *Buchloe dactyloides*, *Bouteloua rigidiseta*, and *Paspalum distichum*, and over 30% in several of the species of tall growth habit. Fiber averaged relatively low in *Cynodon* species and relatively high in *Andropogon*, *Eragrostis*, and *Sporobolus* species. Nitrogen-free extract averaged over 50% in *Cynodon dactylon* (St. Lucy) and *Paspalum distichum*. Nitrogen-free extract averaged from 40 to 42% in most of the young grasses and from 45 to 50% in most mature grasses. Nitrogen-free extract was higher and crude fiber lower in short grasses than in tall grasses.

COMPARISON OF GRASSES AS FORAGE FOR RANGE BEEF ANIMALS

Cattle in the subhumid section of the state are generally superior to those found in the humid section. The question is often raised as to whether this superiority is due chiefly to differences in the chemical composition of the different grasses found on ranges in the two sections. Short grasses, especially buffalo, curly mesquite, and various grama grasses, predominate on the ranges in the subhumid section. Forage on native pastures in the humid section is principally composed of various *Andropogons*, particularly *A. scoparius* and *A. provincialis*, with small amounts of *Sorghastrum nutans*, *Tripsacum dactyloides*, and some of the less desirable *Panicum*, *Paspalum*, and *Eragrostis* species. Nearly all of these species are tall grasses. The data presented in this paper show that, on the same soil and under uniform growth conditions, the grasses commonly found on the unimproved pastures of the humid section are somewhat inferior to those found on the native ranges of the subhumid section, particularly during later stages of growth. Forage on improved pastures of the humid section is made up principally of Bermuda, carpet, and various *Paspalum* grasses, particularly Dallis grass (7). These grasses were superior to the short grasses of the subhumid section in both protein and phosphoric acid when young and in phosphoric acid when mature. Carpet grass, *Axonopus affinis*, was not included in the present study, but other work (3, 4, 7) has shown that this grass is greatly inferior to Bermuda and Dallis grasses.

During the winter and the very dry weather of the summer, the deterioration in all of these grasses on ordinary ranges is considerably

greater than in the grasses of the subhumid section. Moreover, the soils of the humid section of the state are usually much lower in nitrogen, phosphoric acid, potash, and lime than the soils of the subhumid section (2), and hence can usually be expected to produce forage of lower quality, irrespective of the comparative chemical composition of the different species when grown on the same soil.

In general, it may be concluded that, if grown on the same soil, the grasses providing the bulk of the forage on the ranges of the subhumid section are superior to those on the native pastures of the humid section, but may be no better than or sometimes slightly inferior to the grasses found on the improved pastures of the humid section.

SUMMARY

Protein, phosphoric acid, and lime were determined in 336 samples of 64 important species of grasses grown on a Victoria clay loam at San Antonio, Texas, collected on six dates covering a period of over a year. Crude fiber, nitrogen-free extract, water, and ash were determined in 222 of the samples.

Considerable differences in chemical composition were found among the various species of grasses. These differences were found not only among different genera but also among different species of the same genus. Percentages of protein and phosphoric acid were generally relatively high in *Cynodon* and *Paspalum* species and relatively low in *Andropogon*, *Hilaria*, and *Eragrostis* species. Advancing maturity greatly decreased the percentages of protein and phosphoric acid in all species, so that many were deficient for beef cattle in phosphoric acid and protein. The relative decreases differed considerably with differences in genera and species. The relative decrease due to maturity was least in short grasses commonly found in the subhumid section of the state and greatest in tall grasses ordinarily found in the humid section.

Species of grasses of importance to the native pastures of the humid section of the state averaged lower in protein and phosphoric acid and a much larger proportion of the samples were deficient in these constituents than is the case in species of importance to the ranges of the subhumid section. Species ordinarily found on improved pastures of the humid section may be as good as or better than those of the subhumid section.

LITERATURE CITED

1. Brittingham, W. H., and Fudge, J. F. Yield, chemical analysis, and fertilizer response of eleven forage grasses. Tex. Agr. Exp. Sta. Progress Rpt. 875. 1944.
2. Fraps, G. S., and Fudge, J. F. Chemical composition of soils of Texas. Tex. Agr. Exp. Sta. Bul. 549. 1937.
3. ———, ———. The chemical composition of forage grasses of the East Texas Timber Country. Tex. Agr. Exp. Sta. Bul. 582. 1940.
4. Fudge, J. F., and Fraps, G. S. The chemical composition of forage grasses from the Gulf Coast Prairie, as related to soils and to requirements for range cattle. Tex. Agr. Exp. Sta. Bul. 644. 1944.
5. Hafner, V. E. Angleton grass. Tex. Agr. Exp. Sta. Bul. 342. 1926.

6. PIERRE, W. H., and ROBINSON, R. R. The calcium and phosphorus contents of pasture herbage and of various pasture species as affected by fertilization and liming. Jour. Amer. Soc. Agron., 29:477-497. 1937.
7. STANSEL, R. H., REYNOLDS, E. B., and JONES, J. H. Pasture improvement in the Gulf Coast Prairie of Texas. Tex. Agr. Exp. Sta. Bul. 570. 1939.

AN EVALUATION OF KENTUCKY BLUEGRASS[1]

B. A. BROWN AND R. I. MUNSELL[2]

MANY times during the last 20 years, agronomists of the Northeast have spoken disparagingly of Kentucky bluegrass. Some of the shortcomings commonly mentioned are (1) low total yield; (2) little growth in midsummer; (3) unpalatable if not kept short; (4) strong competition for other species, especially legumes; and (5) fertile soils or liberal fertilization necessary.

The authors are among those who have emphasized the weak points of Kentucky bluegrass and have spent much time in testing other grasses. After many years of such work, considerable data have accumulated and these will be summarized in this paper. For the sake of brevity and because of the limited scope of the subject, only results from the "commercial" lots of seed of each species will be considered at this time.

SEASONAL AND TOTAL YIELDS

Four experiments involving Kentucky bluegrass and other grasses have been conducted for two or more years on fields of Charlton fine sandy loam soil on the Station Farm at Storrs, Conn. In the oldest experiment (No. 1 of this paper), nine grasses were sown in pure culture in September, 1935, on soil not limed since 1919 and which had a pH of 5.6 before seeding. Since 1936, duplicate plots of each grass have been exposed to six different treatments in addition to the general PK fertilization. These treatments are (1) none, (2) Kent clover seeded, (3) ladino clover seeded, (4) nitrogen at 28 pounds in April, (5) nitrogen at 28 pounds in April and repeated in June, and (6) nitrogen at 28 pounds in April and repeated in June and August. In all cases, the vegetation was mowed when 4 to 5 inches high by a motor lawnmower set to cut 1 inch above the ground. Under this management, five of the nine grasses soon had such poor stands that their yields will not be presented here. Those five species were Canada bluegrass, *Poa compressa*, tall oat grass, *Arrhenatherum*, meadow fescue, *Festuca pratensis*, smooth brome grass, *Bromus inermis*, and perennial rye grass, *Lolium perenne*.

These and some of the following results corroborate data published by Wiggins in 1923.[3]

The seasonal and total yields of dry matter for the other four grasses under two different types of treatments are presented in Table 1. The data in the table show that, either with ladino clover or alone under intensive nitrogen fertilization, Kentucky bluegrass yielded fully as much dry matter throughout the season as Rhode Island bent grass, orchard grass, or timothy. During the later years

[1]Contribution from the Department of Agronomy, Storrs (Connecticut) Agricultural Experiment Station, Storrs, Conn. Received for publication November 16, 1944.

[2]Associate Agronomist and Assistant Agronomist, respectively.

[3]WIGGANS, R. G. Studies of various factors influencing the yield and the duration of life of meadow and pasture plants. Cornell Univ. Agr. Exp. Sta. Bul. 424. 1923.

of this experiment, timothy had poor stands and considerable Kentucky bluegrass volunteered. To a much lesser extent, this was also true of orchard grass. However, an examination of the results for any one or combination of the seven seasons would lead to the same conclusions as drawn from the summaries in Table 1.

TABLE 1.—*Seasonal and total yields of four grasses in experiment No. 1.*

Grasses seeded*	Pounds of dry matter per acre, ave. 1936–42†						
	Before May 16	May 16–June 15	June 16–July 15	July 16–Aug. 15	Aug. 16–Sept. 15	After Sept. 15	Total
When Ladino Clover was Seeded with Each Grass							
Rhode Island bent	380	701	615	673	479	198	3,046
Kentucky bluegrass	473	789	591	698	462	203	3,216
Orchard grass	332	583	507	514	332	128	2,396
Timothy	416	732	503	553	349	154	2,707
When Each Grass Received 28 lbs. of Nitrogen per Acre in Apr. June, and Aug.‡							
Rhode Island bent	502	700	567	448	445	157	2,819
Kentucky bluegrass	579	674	626	464	447	137	2,927
Orchard grass	605	704	612	399	320	152	2,792
Timothy	739	838	523	390	342	106	2,938

*Each grass was seeded alone in September 1935 and on certain plots, ladino clover was seeded the following spring. The botanical names of the grasses are Rhode Island bent, *Agrostis tenuis;* Kentucky bluegrass, *Poa pratensis;* orchard grass, *Dactylis glomerata;* and timothy, *Phleum pratense.*

†Yields are averages of duplicate, 50 × 8 foot plots, lawnmowed when 4 inches to 1 inch, eight times per season.

‡Nitrogen from calnitro. All plots received superphosphate and muriate of potash before seeding and in 1939, 1940, and 1941. In 1935, the soil, which had been limed last in 1919, had a pH of 5.6.

In a second lawnmowing experiment, several grasses were seeded alone and with Ladino clover on triplicated 40 × 6 foot plots in the spring of 1937. Before seeding, the entire field received limestone at the rate of 2,000 pounds to the acre, 16% superphosphate at 500 pounds, and 50% muriate of potash at 200 pounds. Each year, nitrogen at 28 pounds per acre was applied in April, June, and August to the grasses seeded alone, but no nitrogen was added to the grass-ladino mixtures. The plots were lawnmowed several times that season, but yields were determined on only two dates, July 7 and August 3. The yields were measured from 11 cuttings in 1938 and 7 cuttings in 1939.

The total yields of dry matter for all cuttings weighed during the 3 years are given in Table 2. Where the grasses were seeded alone and received liberal nitrogenous fertilization, Kentucky bluegrass had slightly higher yields than orchard grass and timothy and considerably greater production than Rhode Island bent and perennial rye grasses. Where Ladino was seeded with each grass, Rhode Island bent and timothy yielded about 10% above and orchard and perennial rye grasses slightly below Kentucky bluegrass.

TABLE 2.—*Yields of five grasses in experiment No. 2.*

Grasses seeded	Total pounds of dry matter per acre, 1937–39*		
	Grasses alone plus nitrogen†	Grasses with Ladino	Averages
Kentucky bluegrass	7,202	7,597	7,400
Timothy	6,809	8,248	7,529
Perennial rye‡	5,728	7,183	6,456
Rhode Island bent	6,335	8,306	7,321
Orchard grass	6,918	7,265	7,092

*Total yields from 2 lawnmowings in 1937, 11 in 1938, and 7 in 1939.
†A total of 84 pounds of nitrogen per season, equally divided into April, June, and August applications.
‡English rye grass, *Lolium perenne;* not domestic rye grass.

In the third experiment, started in 1938, Ladino clover was seeded alone, with orchard grass, and with Kentucky bluegrass on a field which had been fertilized liberally for potatoes in 1936 and 1937 and heavily limed in 1938. Each seeding was made on nine 60 × 10 foot plots which, in 1939, were divided into three differently fertilized groups. None of the fertilizers carried nitrogen. In this paper, only the average results for all of the nine plots will be considered.

The plots were cut with a tractor mower four times each season, excepting 1943, when, due to extremely dry weather in August and September, the fourth (October) cutting was omitted. This method of harvesting is, of course, much more favorable for orchard grass and probably for ladino clover than the lawnmowing practiced in the first and second experiments. For this reason and also because in Connecticut orchard grass has been considered more valuable than Kentucky bluegrass for dual purpose hay and pasture seedings, the yields for each cutting during five years (1939–43) are given in Table 3.

In most of the 19 comparisons, ladino alone yielded less, on the average 10 per cent less, than when seeded with either of the grasses. In 11 of the 19 cuttings, the orchard grass mixture yielded more than that with Kentucky bluegrass. Of the 14 comparative yields *after* the *first* cuttings, the orchard grass mixture was superior to the Kentucky bluegrass mixture in 10 cases. The differences were small, however, and the 5-year total yields averaged the same, 4,800 pounds per acre. It should be emphasized that all of this fairly large, annual yield of dry matter, equivalent to 2.75 tons of hay, was high quality forage.

It may be noted that in the *first* cutting of 1943, the yield of the orchard gràss mixture was much less than the one with Kentucky bluegrass. This was due to the orchard grass having suffered considerable weakening and killing during the unusually cold weather of the preceding winter.

In a fourth experiment, 50 varieties and strains of grasses were seeded alone in August 1940 on triplicated 50 × 8 foot plots. Limestone at 1 ton to the acre and 47% superphosphate and 50% muriate of potash at 200 pounds each per acre were disked in before sowing. In both 1941 and 1942, nitrogen at 30 pounds per acre was applied in April and repeated after the first and second cuttings. The plots

TABLE 3.—*Yields of orchard grass and Kentucky bluegrass when seeded with ladino clover and cut four times per season in experiment No. 3.**

Species seeded†	Pounds of dry matter per acre				
	First cutting	Second cutting	Third cutting	Fourth cutting	Totals
		1939			
Ladino alone	657	1,771	1,260	787	4,476
Ladino + orchard grass	1,246	1,989	1,370	1,181	5,786
Ladino + Kentucky bluegrass	1,301	1,857	1,021	1,303	5,482
		1940			
Ladino alone	974	1,936	1,286	788	4,984
Ladino + orchard grass	1,290	1,901	1,438	871	5,500
Ladino + Kentucky bluegrass	1,553	1,792	1,199	677	5,221
		1941			
Ladino alone	1,415	1,308	905	265	3,993
Ladino + orchard grass	1,990	1,675	857	240	4,762
Ladino + Kentucky bluegrass	1,708	1,708	744	336	4,496
		1942			
Ladino alone	2,031	1,347	876	629	4,883
Ladino + orchard grass	2,040	1,499	1,043	739	5,321
Ladino + Kentucky bluegrass	2,262	1,637	908	671	5,478
		1943‡			
Ladino alone	884	1,831	650	—	3,365
Ladino + orchard grass	625	1,458	576	—	2,659
Ladino + Kentucky bluegrass	1,596	1,242	557	—	3,395
		Averages for 5 Years			
Ladino alone	1,192	1,639	995	494	4,320
Ladino + orchard grass	1,438	1,704	1,057	606	4,805
Ladino + Kentucky bluegrass	1,684	1,647	886	597	4,814

*The average dates of cutting were June 5, July 18, August 24, and October 18.
†Ladino alone seeded at 6 pounds, with either grass at 3 pounds. Orchard grass was seeded at 6 pounds, Kentucky bluegrass at 12 pounds.
‡1943 was a very dry season, especially in August and September, and consequently there was too little growth to justify an October cutting.

were tractor mowed for yields on June 3, August 3, and October 21, 1941, and on June 10 and August 21, 1942. Only the results from the "commercial" strains of the common grasses are given in this paper (Table 4).

The larger grasses, timothy, orchard grass, and meadow fescue, had the highest average yields for the first cuttings, but redtop and Kentucky bluegrass were superior for the second crop. On the basis of the total yields for both years, there is little to choose between timothy, Kentucky bluegrass, and orchard grass. Notes taken in July, 1944, show that Kentucky bluegrass and orchard grass were the only ones with more than 50% stands, and there is little doubt that these species would have outyielded the others over a period longer than two years.

TABLE 4.—*Yields of eight grasses in experiment No. 4.**

Grass seeded in Aug., 1940	Pounds dry matter per acre										Stands July 17, 1944, %†
	First cutting			Second cutting			Third cutting, 1941	Totals			
	1941	1942	Av.	1941	1942	Av.		1941	1942	Av.	
Timothy	2,088	2,873	2,481	1,544	788	1,166	266	3,898	3,661	3,780	—
Redtop	1,913	1,925	1,919	1,952	764	1,358	421	4,286	2,689	3,488	45
Smooth brome	1,622	1,595	1,609	1,393	429	911	357	3,372	2,024	2,698	50
Kentucky bluegrass	2,132	1,341	1,737	1,634	1,467	1,551	945	4,711	2,808	3,760	83
Perennial rye‡	4,259	—	—	510	—	—	311	5,080	—	—	—
Orchard grass	2,632	1,649	2,141	1,377	1,078	1,228	689	4,698	2,727	3,713	67
Meadow fescue	3,460	1,517	2,489	754	654	704	857	5,071	2,171	3,621	—

*"Commercial" seed was sown in all cases. In 1941 and 1942, nitrogen was applied at 30 pounds per acre in April and repeated after the first and second cuttings. The dates of cutting were June 3, August 3, and October 21 in 1941; and June 10 and August 21 in 1942.

†Where no value is given, weeds had largely replaced the seeded grass.

‡Perennial (English) rye grass had such a poor stand in 1942 that its yields were not determined

Before leaving the subject of yields, it should be mentioned that in two other experiments involving many fertilizer treatments on adjacent, lawnmowed areas of pure seedings, Rhode Island bent grass consistently yielded more dry matter than Kentucky bluegrass. Rhode Island bent grass is also much less sensitive than Kentucky bluegrass to adverse soil conditions and is almost as winter hardy. These facts suggest that more consideration should be given to the bents for seeded pastures. They already comprise a considerable part of the plant population in the permanent pastures of Connecticut.

QUALITY OF FORAGE

In two experiments in which the forage was lawnmowed, and in two others mowed three or four times per season as early cut hay, the dry matter yields from Kentucky bluegrass were practically as large and as well distributed throughout the season as those from several common grasses. In recent years, *yield of dry matter* as a criterion in evaluating forages has been seriously questioned. The writers think that such a criticism is well founded. The importance of this point, however, depends to a considerable extent on which species and what stages of maturity are involved. For example, the dry matter of most grasses in the young, leafy stage is high in palatability and digestibility. Deterioration of grasses is especially marked after the heading or blossoming stage. Thus, the determination of dry matter yields may be an excellent means of evaluating most grasses and legumes mowed when 4 to 5 inches high, a fairly accurate method until the grasses head and even later for legumes, but a poor measurement of feed production as the plants approach maturity.

Ordinary chemical analyses furnish some indications of forage crop quality. In some years, such analyses were made for the crops in experiments Nos. 1 and 3 and the results are summarized in Tables 5 and 6.

TABLE 5.—*Chemical analyses of four grasses lawnmowed eight times each season.*

Grass	Analyses as percentage of dry matter*						
	Ash	Protein	Fiber	N.F.E.†	Fat	P	Ca
Rhode Island bent..	8.5	20.2	20.5	46.6	4.4	0.39	0.73
Kentucky bluegrass	7.1	20.7	21.4	46.4	4.6	0.38	0.73
Orchard grass......	9.0	22.7	21.0	42.1	5.3	0.49	0.82
Timothy...........	7.0	22.2	19.0	47.3	4.6	0.38	0.85

*Values are averages of 6 to 10 cuttings each year in 1937 and 1938, the only years all of the listed constituents were determined. Grasses received nitrogen at 28 pounds per acre in April, June, and August, or a total of 84 pounds per season. Data from experiment No. 1, for which yields are given in Table 1.
†Nitrogen-free extract.

Based on the chemical analyses in Table 5, the feeding values or *quality* of all grasses lawnmowed eight times per season were very high. Orchard grass had somewhat higher values for total ash, protein, fat, and phosphorus than Rhode Island bent grass, Kentucky bluegrass, and timothy.

The forages harvested in 1940 and 1941 as early cut hay (experiment No. 3) were also very high in feeding values (Table 6). Again the presence of orchard grass raised appreciably the percentage of fat and phosphorus. On the whole, the chemical analyses indicate no important differences in the quality of the immature ladino-orchard grass and the ladino-Kentucky bluegrass hay.

TABLE 6.—*Chemical analyses of ladino-grass seedings cut four times each season.*

Species seeded	Analyses as percentage of dry matter									
	Protein		Fiber		Fat		P		Ca	
	1940*	1941†	1940*	1941†	1940*	1941†	1940*	1941†	1940*	1941†
Ladino alone.....	25.7	26.7	16.6	—	4.0	—	0.37	0.37	1.4	1.5
Ladino + orchard grass..........	20.8	20.4	21.4	—	4.7	—	0.42	0.42	1.1	1.1
Ladino + Kentucky bluegrass	21.1	22.1	21.2	—	4.2	—	0.34	0.38	1.1	1.3

*In 1940, the first cutting was not analyzed and values are averages of the last three cuttings.
†In 1941, values are averages of all four cuttings. No analyses were made for fiber and fat.

STANDS OF LADINO WITH DIFFERENT GRASSES

Legumes have such an important effect on both the quantity and quality of forage from mixed stands that the seeding of *any grass* which would reduce the prevalence of an accompanying legume may well be questioned. In respect to this point, many agronomists, including the writers, *have* questioned the seeding of Kentucky bluegrass.

In the first and third experiments, discussed above, the stands of

ladino clover were estimated twice each season. The average values for each year are in Table 7. In all seedings of both experiments, ladino decreased with age of stand, but the data offer no indications that Kentucky bluegrass was any more responsible than timothy, Rhode Island bent, or orchard grass.

TABLE 7.—*Ladino stands with different grasses.*

Grass seeded with ladino	Area occupied by ladino (estimated percentages)*							
	1936	1937	1938	1939	1940	1941	1942	1943
Experiment No. 1, Lawnmowed Eight Times Each Season								
Rhode Island bent...	73	63	19	34	26	27	42	—
Kentucky bluegrass	95	43	14	33	36	37	40	—
Orchard grass.......	83	52	18	11	25	32	18	—
Timothy...........	83	55	28	46	36	32	22	—
Experiment No. 3, Mowed Four Times Per Season								
None..............	—	—	95	78	60	83	83	44
Orchard grass.......	—	—	88	68	38	40	33	21
Kentucky bluegrass	—	—	89	64	48	41	51	26

*Except in 1936 in experiment No. 1 and in 1938 in experiment No. 3, the values given are averages of two inspections each season.

Further information on the question of legume stands is furnished by another experiment in which ladino was seeded in 1938 on 30 plots each with timothy or orchard grass. Ten different systems of cutting have been under test on both the timothy and orchard grass sections. Very little timothy was obtained from this seeding and partly as a result volunteer Kentucky bluegrass has become quite prevalent there. Orchard grass has maintained good stands under most of the cutting systems and consequently in October 1944 there was only half as much Kentucky bluegrass on the orchard grass plots as on those seeded with timothy. The stands of ladino have been estimated at least twice each season and the annual averages are given in Table 8.

TABLE 8.—*Ladino stands when seeded with timothy or with orchard grass.*

	Area occupied by ladino (estimated percentages)					Volunteer Kentucky bluegrass in Oct., 1944, % of area
	1940	1941	1942	1943	1944	
30 timothy plots.......	45	47	60	26	28	35
30 orchard grass plots...	50	49	57	25	35	18

Only in 1944 were the stands of ladino appreciably less on the timothy, well mixed with volunteer bluegrass, plots than on the orchard grass section where bluegrass was 50% less prevalent. Probably at least part of the explanation for this difference in 1944 was

the spotty killing of orchard grass during the severe winter of 1942 and 1943. Due to little competition from any grasses, such spots were almost 100% ladino in 1944.

DISCUSSION

The preceding data from several experiments are consistent in showing that Kentucky bluegrass, either alone with nitrogenous fertilizers or in ladino clover mixtures, has yielded as much dry matter of nearly equal feeding quality, as orchard grass, Rhode Island bent grass, or timothy. Under all systems of mowing, it maintained better stands than the other grasses and when seeded with ladino clover did not reduce the prevalence of that legume more than the other grasses.

It should be understood, however, that in all of these experiments, the crops were harvested by machines and entirely removed from the land. In addition, when harvested as hay, the first cutting was earlier and the others more frequent than is customary, and no doubt this management favored Kentucky bluegrass in these tests. Furthermore, the fertilizers applied to the grass-clover plots contained no nitrogen, although if one considers the large amounts of nitrogen furnished by legumes to accompanying grasses, the part played by nitrogen from fertilizers or manure in increasing the competition of grasses in grass-legume mixtures decreases in importance. Regardless of the nitrogen situation, legumes are very sensitive to low levels of available potash in the soil, a condition all too prevalent on Northeastern farms, where for generations, much of the potash in manure has not been returned to the land. On the other hand, Kentucky bluegrass is much less dependent than legumes on the potash from manures and fertilizers. Thus, the limed-phosphated soils of long-tilled fields in this region may be much more favorable for grasses than for legumes. This unbalanced condition of the soil may be accentuated on poultry farms, for the droppings are much higher in nitrogen and phosphorus than in potassium. For this reason and also because poultry makes little use of grasses not kept in a lawn-like condition, it may be a better practice on poultry farms to make pure seedings of ladino or other legumes.

The question of pure legume or grass-legume seedings is also a pertinent one where such crops are consumed by cattle. Existing evidence shows the ladino-grass seedings have several important advantages over ladino alone, including (1) larger yields of dry matter from early cut hay or rotationally grazed pasture; (2) better balanced feed; (3) less winterkilling, particularly by heaving of the clover, this being more important on heavy or wet soils; (4) facilitation of haying operations, especially curing; (5) less likelihood of complete crop failure; (6) fewer weeds.

The high level of soil fertility required by Kentucky bluegrass has been mentioned as one of its disadvantages. Unless one is attempting to grow crops which will exist on a low plane of fertility and accept the correspondingly low quantity and quality of forages produced under such conditions, this point seems to have little weight. In the experiments conducted at Storrs, Kentucky bluegrass has thrived where the

soil was favorable for red and ladino clovers or timothy. Alsike clover and members of the Agrostis genus (redtop, bents, etc.) will grow fairly well where the soil is too acid and wet for Kentucky bluegrass. Redtop and the bents will also survive with less easily soluble phosphorus in the soil than is required by Kentucky bluegrass. Farm experience in Connecticut appears to indicate that orchard grass is superior to Kentucky bluegrass on sandy soils.

The slowness with which Kentucky bluegrass becomes established is another disadvantage. When seeded in the spring with clovers, little bluegrass will be found in the crop that year. Even with late summer seedings, the hay or pasture is likely to be mostly leguminous during the next season. In many cases, this will also result with other grasses. Where ladino clover is the legume seeded with Kentucky bluegrass, the difficulties of harvesting or grazing it the first season, when little grass is present, are likely to be realized.

Kentucky bluegrass is favored by cool weather and starts growth, reaches the heading stage, and matures relatively early in the season. It is necessary, therefore, to graze or mow relatively early in the season to avoid poor quality pasture or hay; however, the same precaution should be taken with orchard grass and, later in the season, with other grasses.

The most favorable characteristic of Kentucky bluegrass as a grass for livestock farms in the Northeast is its ability to maintain good stands under most any kind of management or weather conditions, provided a reasonable level of fertility exists in the soil. In this respect, none of the other common grasses equal it. For this, if for no other reason, Kentucky bluegrass should be given serious consideration when seeding land which one does not care to till again for many years.

SUMMARY

This paper presents the results of four experiments involving comparisons of Kentucky bluegrass with other grasses common to the Northeast. In two experiments, the plots were lawnmowed 4 to 1 inches and in the other experiments mowed three or four times each season as early cut hay. In three of the four experiments, Kentucky bluegrass and the other grasses were in pure cultures, receiving nitrogen at 28 pounds three times each season, and also seeded with ladino clover.

By both systems of harvesting, the quantity and quality of forage from Kentucky bluegrass were practically equal to orchard grass, Rhode Island bent grass, and timothy. The seasonal distribution of forage production was not appreciably different from the other grasses.

Ladino clover maintained its stand as well when seeded with Kentucky bluegrass as with any of the grasses usually grown in this region for hay or pasture. Kentucky bluegrass has maintained much better stands than any of the other grasses.

It is concluded that Kentucky bluegrass should be given serious consideration in seed mixtures for pasture and early cut hay in the Northeast, particularly in long rotation or semi-permanent grassland.

BEHAVIOR OF VARIOUS SELECTIONS OF KENTUCKY BLUEGRASS, *POA PRATENSIS* L., WHEN GROWN AS SPACED PLANTS AND IN MASS SEEDINGS[1]

H. L. AHLGREN, D. C. SMITH, AND E. L. NIELSEN[2]

KENTUCKY bluegrass, *Poa pratensis* L., is probably the most important source of pasturage in nearly all the north, humid region of the United States, in eastern Canada, and in northern Europe. During the past 8 to 10 years increased efforts have been made by investigators in these areas to develop superior varieties of bluegrass for use as pasturage. Thus far no improved strains are grown commercially to any considerable extent in North America. Nilsson-Leissner and Nilsson (2)[3] have reported that five varieties of Kentucky bluegrass were released in Sweden prior to 1940. Observations indicate that improved European varieties have no particular superiority in Wisconsin.

Myers and Garber (3) reported results of studies of replicated clonal plots from 81 selected plants of Kentucky bluegrass. The plots were overseeded with white clover. Following two years of clipping, simulating pasture treatment, yields were determined in the third season. Significant differences among strains for yield and competitive ability with white clover were noted.

Hayes and Thomas (1) found that different clones of Kentucky bluegrass obtained from 150 pastures and waste places in Minnesota showed wide differences in yielding ability when grown in clonal plots. There was good agreement in yield between 1941 and 1942 from clonal plots established in the fall of 1939. In another trial, Hayes and Thomas (1) grew 56 selected lots of Kentucky bluegrass from seed in replicated plots 8 by 8 feet in size. Their results show that five strains were superior in total production to the commercial check at the 5% level of significance. The seedings were made in the fall of 1943 and results are based on yields obtained in 1944. While several other workers have isolated apparently superior types for pasture or turf purposes, reports of experimental pasture tests of such isolates are unavailable.

The large number of selections which need to be tested in a breeding program involving the improvement of bluegrass and the small amount of seed which is usually available almost necessitates making initial selections of superior appearing plants from spaced plantings

---

[1]Contribution No. 196 from the Department of Agronomy, University of Wisconsin, Madison, Wis., in cooperation with the Division of Forage Crops and Diseases, Bureau of Plant Industry, Soils and Agricultural Engineering, U. S. Dept. of Agriculture. Published by permission of the Director of the Wisconsin Agricultural Experiment Station. Received for publication November 16, 1944.

[2]Associate Professors of Agronomy, University of Wisconsin, and Associate Agronomist, Division of Forage Crops and Diseases, Bureau of Plant Industry, Soils and Agricultural Engineering, U. S. Dept. of Agriculture, respectively. Dr. O. S. Aamodt, formerly professor of Agronomy at the University of Wisconsin, and the late Dr. F. W. Tinney, Assistant Agronomist, Bureau of Plant Industry, U. S. Dept. of Agriculture, were in charge of the nurseries during the period 1936 to 1939, inclusive.

[3]Figures in parenthesis refer to "Literature Cited", p. 281.

in nursery rows. This procedure is followed even though it is recognized that to be of value for forage purposes such selections must ultimately perform satisfactorily in mass seedings. In studies with small grains, many workers have found good agreement to exist when grain yields from rod-row plots have been compared with those of field plots and quadrats. Tysdal and Kiesselbach (5) and Weihing and Robertson (6) have reported that either nursery rows or plots may be satisfactorily used in the evaluation of varieties of alfalfa. Other workers have suggested that spaced plants and comparable plants grown in mass seedings might behave differently. As far as is known, however, no previous investigations have been conducted in which the comparative performances of various strains of bluegrass grown from seed in space-planted rows and in mass seedings in plots have been ascertained. The primary objectives of the studies being reported were (a) to develop superior strains of bluegrass for pasture purposes, and (b) to compare the performance of various selections of bluegrass when grown in space-planted nursery rows and in mass seedings.

MATERIALS AND METHODS

NURSERY TRIALS

Approximately 11,800 plants representing 490 progenies of Kentucky bluegrass were grown in nursery rows on the University Hill Farms at Madison, Wisc., during the period 1936–39, inclusive. The progenies were from collections made in Wisconsin, Minnesota, Nebraska, Montana, Utah, Canada, Norway, Sweden, England, India, and Russia (Table 1).

TABLE 1.—*Sources and numbers of collections of Kentucky bluegrass studied at Madison, Wisc., during the years 1936–39, inclusive.*

Year	Wisconsin	Other states	Other countries
1936	20	—	4
1937	133	—	19
1938	61	18	1
1939	139	74	21
Total	353	92	45

The collections made in Wisconsin were primarily from old pastures in areas within the state representing the major soil types. The seeds from single inflorescences were harvested separately. The collections from other states and foreign countries were, in most instances, grown from bulk sample lots.

Seeds from each inflorescence and from the bulk lots were germinated in the greenhouse in small bread pans filled with friable, autoclaved soil. After the seedlings were well rooted, representative seedlings were transplanted singly into small paper bands filled with autoclaved soil. Seedlings were grown in the greenhouse in paper bands until early May when they were transplanted to nursery rows in the field. Plants were spaced at 2-foot intervals in rows 3½ feet apart. Twenty-four seedling plants of each lot were grown. Notes on plant type, disease reactions, spreading ability, culm height, leafiness, and seed production were taken during the first and second years.

SMALL PLOT INVESTIGATIONS

Seventy-four of the progenies grown in the various breeding nurseries appeared sufficiently promising from the standpoint of uniformity of type, leafiness, aggressiveness, disease resistance, and general growth habit to warrant further investi-

gation in broadcast or mass seedlings in small plot trials. Twenty-five of these selections and commercial bluegrass were seeded in plots 8 by 20 feet in size in relatively infertile Miami silt loam soil on August 15, 1939 (experiment I). The plots were arranged in a randomized block design with four replications. Seedings were at the rate of 40 pounds of rough-threshed seed per acre. Very little growth was made by most of the selections in 1940. Except for mowing in August to remove weed growth, no other treatment was given these plots in 1940. Ammonium sulfate was applied to all plots at the rate of 200 pounds per acre in early spring each year during the period 1941–43, inclusive. The plots were grazed periodically each year during this period by dairy heifers. Observations on yield, leafiness, height, percentage of forage removed after grazing, ground cover, and disease reaction were made prior to each grazing period during each season.

Fifty-four selections of bluegrass and one commercial lot were seeded in plots 6 by 12 feet in size in relatively fertile Carrington silt loam soil on August 17, 1940 (experiment II). The plots were arranged in a randomized block design with four replications. Twenty additional selections of bluegrass of which there was insufficient seed for the establishment of quadruplicate plots were seeded in duplicate plots of similar size in an adjoining area (experiment III). The seedings were made at the rate of 40 pounds of rough-threshed seed per acre. One half of each plot in both the quadruplicate (experiment II) and duplicate (experiment III) series was seeded to common white clover at the rate of 5 pounds per acre. The plots were grazed or mowed periodically each year during the period of 1941–43, inclusive.

Estimates of yield, competitive ability with white clover, and disease reaction were made 2 or 3 times each year during this period. The actual yields of forage from the portions of each plot seeded to grass alone were determined in 1941 and 1942. In 1941 a quadrat 4 feet square was harvested from each plot for calculating yield of dry matter. Because of encroachment of white clover into the margins of the grass portions of the plots, it was necessary to reduce the size of the quadrats harvested in 1942 to 4 square feet. In 1943, actual yields of forage produced by the various selections of bluegrass were not determined. At this time most of the portions of the plots originally seeded to grass alone were occupied by heavy growths of white clover. Conversely, there was little or no white clover in the portions of the plots which were initially seeded to a mixture of grass and white clover.

Twenty-four seedling plants of each of the 74 selections of bluegrass were transplanted to single nursery rows in relatively fertile Carrington silt loam soil in the spring of 1941. These progenies were established to make comparisons and correlations of the behavior of plants grown in mass seedings and in space-planted rows. During the summers of 1941 and 1942 estimates were made of the vigor, habit of growth, leafiness, and disease reactions of the various progenies.

METHODS OF EVALUATION

In estimating yields, competitive ability with white clover, degree of grazing, vigor, and leafiness, a scale of 0 to 10 was used. In estimating disease reaction a scale of 0 to 5 was used. Lower values given in the tables represent superior qualities, i.e., higher yields, greater freedom from disease, and more complete utilization in grazing, whereas the higher values represent progressively inferior qualities, i.e., lower yields, less freedom from disease, and less utilization in grazing.

RESULTS

YIELDS OF FORAGE PRODUCED BY VARIOUS SELECTIONS GROWN IN MASS SEEDINGS

To test the value of results obtained by estimation, comparisons of the actual and estimated yields of forage produced by the 74 selections of bluegrass and commercial bluegrass included in experiments II and III were made in 1941 and 1942. In all instances yields were

estimated 2 or 3 days prior to the time that samples were taken for actual dry matter determinations. Because of the similarity and close agreement of the data in experiments II and III, only that for experiment II is reported. Values of r = .73 and r = .80 were obtained in 1941 and 1942, respectively, when the actual and estimated yields of the 54 selections represented in experiment II were compared (Table 5). It is clear from these results that there was a generally good correlation between actual and estimated yields. On the basis of these results it has been assumed that the data based on estimation are helpful for purposes of evaluation.

The actual and estimated yields of forage produced by the 54 selections of bluegrass and commercial bluegrass included in experiment II are indicated in Table 2. The minimum differences required for significance were 253 and 750 pounds per acre in 1941 and 1942, respectively. The estimated yields of forage produced by the 25 selections grown in relatively infertile soil (experiment I) are indicated in Table 3. All of the selections which were scored 2 or more numbers lower and 2 or more numbers higher than commercial bluegrass in the columns of estimated yields in Tables 2 and 3 were considered, respectively, superior and inferior in yield to commercial bluegrass. Very marked differences in volume of growth among the selections were noted at the end of the growing period in seedings made in August. That these initial differences were not maintained is evident from the data given in Tables 2 and 3. The data show that on the basis of estimated yields in 1941, 18 selections in experiment II, 6 selections in experiment III, and 8 selections in experiment I were more productive than commercial bluegrass. In 1942, however, only six of the selections in experiment II, three of those in experiment III, and two of the selections included in experiment I were more productive than commercial bluegrass. Likewise, in 1943, only three of the selections in experiment II and two of the selections in experiment I were more productive than the commercial lot. Data relative to the estimated yields of the various selections which are given in Tables 2 and 3 indicate that only one of the 74 selections of bluegrass (P No. 17) was superior to commercial bluegrass in all 3 years on both soil types. Seven of the selections of bluegrass (P Nos. 33, 57, 61, 63, 81, 85, and 86) were superior to commercial bluegrass in 1941 and 1942 but not in 1943 when grown on relatively fertile soil. One of this group (P No. 63) was superior to commercial bluegrass in 1941 and 1942 but not in 1943 on both soil types. These data show that there was a marked tendency for original differences between most strains to become less pronounced as seedings increased in age.

YIELD AS INFLUENCED BY YEARS AND SOIL TYPES

The data which are presented in Tables 2 and 3 show that there were many instances of changes in the order of yield of the selections between the 1941 and 1942 growing periods. Of the 24 selections in experiment II which produced more forage than commercial bluegrass in 1941, only 7 were more productive than commercial bluegrass in 1942. Likewise, of the five selections in experiment III which

TABLE 2.—*Calculated yields of dry matter, estimated relative yields, competitive ability with white clover, and reactions to diseases of 54 selections of Kentucky bluegrass and commercial Kentucky bluegrass when grown in small plots in relatively fertile Carrington silt loam soil, 1941–43, experiment II.*

Origin	P No.	Actual yield in pounds per acre		Estimated yield index			Competitive ability with white clover			Reaction to diseases‡			
		1941*	1942†	1941	1942	1943	1941	1942	1943	Leaf spot	Mildew	Leaf rusts	Stripe smut
O. A. C. 1 (Guelph)	1	2,234	1,470	5	7	7	8	5	4	4	0	0	0
O. A. C. 2 (Guelph)	2	2,411	1,851	2	7	7	7	5	7	3	0	2	1
Norway	3	2,574	1,824	3	7	4	8	8	6	2	0	3	1
Sweden (Svalof)	4	1,689	3,075	5	4	4	5	5	3	2	0	2	0
Sweden (Landskrona)	6	2,452	1,933	2	6	5	7	8	7	3	0	3	0
Sweden (Landskrona)	7	1,716	2,232	5	6	6	7	4	3	2	0	0	0
Sweden (Landskrona)	8	2,138	2,123	2	6	6	3	5	4	3	0	3	0
F. C. 22190 (Raskilde, Denmark)	9	1,920	2,150	6	7	5	8	8	7	4	0	0	0
Guelph, Ontario	10	2,622	1,551	3	8	6	8	5	6	4	0	0	0
Guelph, Ontario	11	2,172	1,960	3	6	5	7	8	6	4	0	0	0
Ottawa, Canada	12	1,968	1,551	3	8	7	8	8	6	4	0	0	0
Ottawa, Canada	13	2,104	1,960	4	6	5	8	8	7	4	0	0	0
Ottawa, Canada	14	2,023	1,660	3	7	5	8	5	4	4	0	0	0
Ottawa, Canada	15	1,600	2,838	4	4	4	6	5	3	4	0	1	0
Ottawa, Canada	16	1,743	2,613	6	4	2	6	5	3	4	0	0	0
Ottawa, Canada	17	2,220	3,104	2	2	1	2	4	2	3	0	3	3
Ottawa, Canada	18	1,750	2,368	5	4	3	6	4	5	1	0	2	0
Ottawa, Canada	19	1,648	2,559	5	6	4	8	5	4	2	1	3	1
Ottawa, Canada	20	1,301	2,477	8	4	4	6	8	7	4	0	4	1
Ottawa, Canada	21	1,696	2,477	4	5	6	5	2	5	3	0	0	0
Kewaunee, Wis.	25	1,846	1,987	3	6	5	6	4	5	3	0	4	0

Portage, Wis.	26	1,737	2,804	6	4	4	7	5	4	3	0	2	0
Spooner, Wis.	30	1,403	2,368	7	5	4	8	4	4	3	0	4	3
Ashland, Wis.	35	2,043	1,633	5	8	7	8	5	5	4	0	0	0
Hurley, Wis.	36	1,941	2,531	4	4	3	8	8	6	3	0	3	0
Rhinelander, Wis.	41	1,811	2,613	4	6	7	8	5	5	3	0	1	0
Ottawa, Canada	55	1,735	2,450	5	5	2	7	4	3	2	0	0	3
Ottawa, Canada	56	1,375	2,041	6	5	4	6	4	3	3	0	2	0
Ottawa, Canada	57	1,817	2,776	2	2	5	2	2	2	4	0	1	2
Ottawa, Canada	58	1,511	2,668	6	4	5	8	5	3	2	0	3	0
Barksdale, Wis.	60	1,994	2,259	3	4	3	2	4	4	4	0	1	0
Barksdale, Wis.	61	2,688	2,831	2	3	4	2	5	5	4	0	1	2
Washburn, Wis.	63	1,675	2,695	3	3	3	2	5	2	3	0	4	0
Cornucopia, Wis.	64	1,920	1,470	5	7	6	8	5	5	4	0	0	0
Solon Springs, Wis.	65	1,784	2,531	5	4	3	5	2	2	1	0	1	0
Solon Springs, Wis.	66	1,614	2,749	5	5	3	5	5	4	1	0	1	0
Solon Springs, Wis.	67	1,580	2,804	5	4	4	5	5	3	3	0	1	0
No. Logan, Utah	68	1,606	3,049	4	4	3	3	2	2	4	0	3	0
W. Wellsville, Utah	69	1,681	2,314	5	5	4	7	4	2	3	0	1	0
Bozeman, Mont.	70	1,484	2,150	6	5	7	7	4	5	3	0	3	0
Bozeman, Mont.	71	1,742	2,014	5	5	3	8	8	4	3	0	0	0
Southern Iowa	72	1,307	2,803	8	6	8	8	5	6	3	0	3	0
Columbia, Mo.	73	1,388	2,232	7	6	5	8	4	4	4	3	0	0
PEI 130,449 (Landskrona, Sweden)	74	2,055	2,259	2	5	4	5	5	4	3	0	0	0
FC22598 (Landskrona, Sweden)	75	1,987	2,123	3	6	5	5	5	6	3	0	0	0
Kaukauna, Wis.	77	1,776	3,076	5	4	4	3	4	3	4	0	2	0
Kaukauna, Wis.	78	1,921	2,641	5	6	5	2	4	4	3	0	2	0
Kaukauna, Wis.	79	1,572	2,504	6	5	5	5	2	3	3	0	1	0
Kaukauna, Wis.	80	1,613	2,259	6	4	5	5	5	2	4	0	1	0
Kaukauna, Wis.	81	1,912	3,021	2	3	3	2	7	4	4	0	1	2
Kaukauna, Wis.	82	1,654	2,586	4	4	4	2	5	3	3	0	2	3
Kaukauna, Wis.	83	1,695	1,715	5	6	5	5	5	3	4	0	3	0
Kaukauna, Wis.	84	1,511	1,960	7	6	4	8	8	6	3	0	4	1
Monroe, Wis.	86	1,735	2,477	3	3	4	4	5	3	1	0	4	0
Commercial	—	1,798	2,395	5	5	4	6	8	2	2	0	2	0

*Minimum difference required for significance at the 5% point = 253 pounds.
†Minimum difference required for significance at the 5% point = 750 pounds.
‡The maximum of disease noted in any year during the period 1941–43, inclusive, is indicated.

TABLE 3.—*Estimated yields, relative maturity, and degree of grazing of 25 selections of Kentucky bluegrass and commercial Kentucky bluegrass when grown in small plots in relatively infertile Miami silt loam soil, 1941–1943, experiment I.*

P No.	Estimated yield			Relative maturity		Degree of grazing		
	1941	1942	1943	1941*	1942*	1941	1942	1943
10	5	9	9	1	1	1	1	2
11	5	7	9	1	1	1	1	2
12	6	9	9	1	1	1	1	2
13	9	9	9	1	1	1	1	2
14	4	9	9	1	1	1	1	2
15	3	4	5	2	2	6	9	6
16	3	4	4	2	2	8	7	8
17	1	2	3	2	2	5	8	5
18	1	4	4	2	3	8	9	8
19	4	6	8	2	1	8	5	3
20	6	4	5	3	3	9	9	8
21	4	4	6	2	1	5	5	4
55	1	4	5	2	3	8	9	6
56	3	4	5	2	2	5	5	3
57	2	3	5	3	3	8	8	4
58	5	4	6	3	3	8	9	7
60	2	3	5	2	2	7	8	4
61	2	3	5	2	2	7	7	4
63	2	1	3	3	3	9	9	6
64	3	6	9	1	1	3	4	2
65	2	5	5	3	3	8	9	7
66	3	5	6	2	3	9	9	5
67	3	4	4	2	3	8	9	7
54	4	4	6	3	3	8	9	5
59	3	6	5	2	3	8	9	7
Commercial	4	4	5	3	3	9	9	7

*1 = Late maturity; 2 = Medium maturity; 3 = Early maturity.

produced more forage than commercial bluegrass in 1941, only two were more productive in 1942.

Data in Table 5 show that there was little or no relation between yields of the selections in the first (1941) and second (1942) harvest years when grown in small plots in relatively fertile soil (experiment II). Values of r obtained when comparisons were made between estimated yields in 1941–42 and actual yields in 1941–42 were .07 and –.36, respectively. However, a significant positive correlation ($r = .68$) was obtained in comparing the estimated yields of 25 selections grown in relatively infertile soil during the same years (experiment I). While these data suggest that selections of bluegrass may behave differently in soils of varying fertility, the comparisons may not be entirely valid inasmuch as they are based on results obtained during the second and third years following seeding in the relatively infertile soil and the first and second years following seeding in the relatively fertile soil. This discrepancy in comparisons was due to slow establishment following seeding in the relatively infertile soil. No attempt was made to evaluate the sparse growth made by the selections at that time.

A highly significant, positive correlation (r = .66) was found in experiment II when the estimated yields of the 54 selections grown in small plots in 1942 (second harvest year) and 1943 (third harvest year) were compared. Likewise, there was a good relation between yields during the second and third (r = .68) and third and fourth (r = .89) harvest years of the 25 selections included in experiment I. When estimated yields of the 25 selections grown in relatively fertile soil (experiment II) were compared with those of the same selections grown in relatively infertile soil (experiment I), highly significant correlations of r = .90 and r = .74 were obtained in 1942 and 1943, respectively.

COMPARISONS BETWEEN YIELDS, RELATIVE MATURITY, AND DEGREE OF GRAZING

Data in experiment I, given in Tables 3 and 6, show significant negative correlations between estimated yields of the selections and degree of grazing in 1941, 1942, and 1943. In most instances the forage was grazed more completely in plots in which low yielding selections were grown than in plots occupied by higher yielding types. In addition there was a good relation between the relative maturity of the selections and their respective yields, the later maturing ones being less productive than earlier maturing types. It appears from these results that later maturing selections of bluegrass may be palatable for longer periods in the spring, but less productive than earlier maturing types.

COMPETITIVE ABILITY WITH WHITE CLOVER

Data were obtained in 1941, 1942, and 1943 to determine the competitive ability of the 54 selections of bluegrass and commercial bluegrass with white clover when grown in small plots in relatively fertile soil (experiment II). These data are given in Table 2. In general they indicate that there were marked differences in the ability of the selections to compete with white clover. Although the taller growing, more productive selections were stronger competitors with white clover than shorter growing, less productive types, the correlations obtained when comparisons were made between actual and estimated yields, on the one hand, and competitive ability with white clover, on the other hand, were so low as to be of no value for purposes of prediction (Table 5). It is also of interest to note (Table 5) that while significant, positive correlations were obtained when comparisons were made between results secured in different years with respect to the competitive ability of the bluegrass selections with white clover, in general the values were so low as to be of no practical importance in predicting the performance of bluegrass when grown in association with white clover. It appears from these results that factors other than yielding ability are of considerable importance in affecting the behavior of various selections of bluegrass grown in association with white clover.

DISEASE REACTION

The principal diseases occurring on bluegrass at Madison, Wisc., are leaf spot, *Helminthosporium vagans* Drechl., leaf rusts, *Puccinia rubigo-vera* (D.C.) Wint. and *P. Poae-sudeticae* West., and mildew, *Erysiphe graminis* D.C. Although not as widespread as the other diseases, stripe smut, *Ustilago striaeformis* (West) Niess., was noted in 1942 and 1943. Under conditions such as prevailed during the period 1936 to 1943 at Madison, diseases have not appeared to greatly affect growth and reproduction in pastures although considerable damage has been observed in small localized spots. Nursery trials, however, have shown that some genotypes are very susceptible to diseases in particular seasons. Both leafspot and mildew may affect plants markedly and mildew and rust may develop at any time during the growing season. In 1942, almost every selection of bluegrass was affected to some extent by leaf rust. In contrast, many selections were very resistant to leaf spot and mildew.

Data were obtained in 1941, 1942, and 1943 to determine the disease reactions of the 74 selections of bluegrass grown in relatively fertile soil. As previously indicated, there was close agreement between the results obtained in experiments II and III. For this reason results obtained in experiment III were not included in Tables 2 and 4. Marked differences are indicated in the disease reactions of the various selections in both the nursery rows and mass seedings. Susceptible genotypes were generally more severely infested with disease when grown as spaced plants in nursery rows than in mass seedings in small plots. Portions of plots in which only grass was seeded appeared to be more diseased than the portions of the plots in which the grass was growing in association with clover. Data presented in Table 5 show that there was no close relation between the actual yields of the selections grown in small plots and disease reaction in 1941 and 1942. For example, r values obtained when comparisons were made between actual yields and reaction to leaf rust in 1941 and 1942 were .27 and -.27, respectively. Likewise, r values obtained when comparisons were made between actual yields and reaction to leaf spot in 1941 and 1942 were, respectively, .17 and -.23. It would appear from these results, that, on the average, disease had no major affect on plot yields of the various selections of bluegrass although in some selections field observations seemed to indicate that disease was causing considerable damage. It is recognized, however, that under different soil and climatic conditions or in seasons differing from those which existed during the course of these studies, disease may be of greater importance in affecting yields of Kentucky bluegrass than the data given indicate.

COMPARISONS BETWEEN SELECTIONS GROWN IN SPACE-PLANTED NURSERY ROWS AND IN MASS SEEDINGS

The estimated yields and disease reactions of 54 selections in 1941 and 1942 when grown in space plantings and mass seedings (experiment II) are given in Tables 2 and 4. The data indicate that there were considerable differences in the behavior of the selections with

TABLE 4.—*Estimated yields and reactions to mildew, rust, leaf spot, and stripe smut of 54 selections of Kentucky bluegrass when grown in space-planted nursery rows in relatively fertile Carrington silt loam soil, 1941–42.*

P No.	Estimated yield		Reactions to diseases*				P No.	Estimated yield		Reactions to diseases*			
	1941	1942	Leaf spot	Mildew	Leaf rusts	Stripe smut		1941	1942	Leaf spot	Mildew	Leaf rusts	Stripe smut
1	9	7	3	0	2	0	56	8	5	1	0	4	0
2	3	5	1	2	2	0	57	6	3	3	2	4	0
3	5	9	2	3	3	0	58	9	5	1	0	4	0
4	2	7	0	2	4	0	60	2	1	3	2	3	1
6	4	7	1	2	3	0	61	2	3	3	2	3	1
7	1	5	2	0	3	0	63	2	5	3	2	4	0
8	5	5	1	0	2	0	64	8	5	2	0	4	0
9	6	3	1	2	1	0	65	2	5	1	2	2	0
10	9	7	1	0	1	0	66	5	5	1	0	2	0
11	3	5	0	2	2	0	67	5	5	1	0	2	0
12	9	3	1	2	1	0	68	5	5	1	2	3	0
13	9	5	1	0	1	0	69	2	3	1	0	3	0
14	9	5	0	0	1	0	70	6	2	1	0	4	0
15	4	3	3	3	3	0	71	5	3	2	0	2	0
16	3	5	3	2	3	0	72	5	1	2	2	3	0
17	2	3	3	0	3	0	73	5	5	4	0	2	0
18	6	5	2	0	3	0	74	4	5	0	0	2	0
19	8	7	2	0	3	0	75	4	5	1	0	1	0
20	5	9	2	0	4	0	77	5	5	1	0	4	0
21	6	5	1	0	4	0	78	2	3	2	0	4	0
25	1	3	1	0	4	0	79	5	5	2	0	4	1
26	6	7	3	2	3	0	80	5	5	1	2	4	0
30	5	5	0	2	3	0	81	2	1	3	0	4	2
35	6	5	0	0	3	0	82	5	5	2	0	4	0
36	4	3	1	0	3	0	83	2	5	1	2	4	0
41	5	5	1	0	3	0	84	9	5	2	3	4	0
55	9	5	2	0	2	0	86	2	5	2	0	4	0

*The maximum of disease noted in any year during the period 1941–42, inclusive, is indicated.

TABLE 5.—*Simple correlation coefficients for various comparisons made between 54 selections of Kentucky bluegrass grown in relatively fertile Carrington silt loam soil during 1941–43, inclusive, experiment II.*

Comparison	r values*
Estimated yields in 1941 and actual yields in 1941	+0.73
Estimated yields in 1942 and actual yields in 1942	+0.80
Estimated yields in 1941 and estimated yields in 1942	+0.07
Actual yields in 1941 and actual yields in 1942	−0.36
Estimated yields in 1942 and estimated yields in 1943	+0.66
Estimated yields in nursery row and estimated yields in plots in 1941	+0.26
Estimated yields in nursery rows and estimated yields in plots in 1942	+0.23
Estimated yields in nursery rows and actual yields in plots in 1941	+0.06
Estimated yields in nursery rows and actual yields in plots in 1942	+0.21
Estimated yields and competitive ability with white clover in 1941	+0.42
Estimated yields and competitive ability with white clover in 1942	+0.31
Estimated yields and competitive ability with white clover in 1943	+0.43
Actual yields and competitive ability with white clover in 1941	+0.04
Actual yields and competitive ability with white clover in 1942	+0.57
Competitive ability with white clover in 1941 and competitive ability with white clover in 1942	+0.40
Competitive ability with white clover in 1942 and competitive ability with white clover in 1943	+0.64
Leaf spot in nursery rows and leaf spot in plots	+0.11
Leaf rust in nursery rows and leaf rust in plots	+0.55
Actual yields and leaf rust in plots in 1941	+0.27
Actual yields and leaf rust in plots in 1942	−0.27
Actual yields and leaf spot in plots in 1941	+0.17
Actual yields and leaf spot in plots in 1942	−0.23

*5% level of significance for 54 pairs of comparisons = 0.27.
1% level of significance for 54 pairs of comparisons = 0.34.

respect to yield and disease reaction when grown in space-planted rows and in mass seedings. For example, of the 11 selections which were significantly more productive than commercial bluegrass in 1941 when grown in mass seedings, only 2 were classified as superior in the space-planted nursery rows. Data presented in Table 5 show that there were no significant correlations between either the estimated or actual yields of the selections grown in mass seedings and the yields of the same selections in nursery rows. Further, no relation was observed between the incidence of leaf spot in the mass-seeded plots and that in the space-planted nursery rows. There was a significant positive correlation between the occurrence of leaf rust in the mass-seeded plots and that in space-planted nursery rows. It is concluded from the data which have been obtained in these comparisons that growth and appearance of spaced plants of bluegrass cannot be used to predict closely the performance of the same progenies in mass seedings. It is apparent that improved technics would be desirable in the initial phases of breeding programs involving the improvement of bluegrass.

DISCUSSION

The tendency for original differences between most strains to become less pronounced as the stands increased in age might have been due in part to accumulating deficiencies of available nitrogen. Even with nitrogen fertilization, however, it was not possible to

TABLE 6.—*Simple correlation coefficients for various comparisons made between 25 selections of Kentucky bluegrass grown in both relatively fertile Carrington silt loam soil and relatively infertile Miami silt loam soil during 1941–43, inclusive, experiments I and II.*

Comparison	r values*
Estimated yields in nursery rows (fertile soil) and estimated yields in plots (relatively infertile soil) in 1941	+0.46
Estimated yields in nursery rows (fertile soil) and estimated yields in plots (relatively infertile soil) in 1942	+0.16
Estimated yields in nursery rows (fertile soil) and estimated yields in plots (fertile soil) in 1941	+0.19
Estimated yields in nursery rows (fertile soil) and estimated yields in plots (fertile soil) in 1942	+0.26
Estimated yields in nursery rows in 1941 and 1942	+0.38
Estimated yields in plots in 1941 and 1942 (fertile soil)	+0.05
Estimated yields in plots in 1942 and 1943 (fertile soil)	+0.61
Estimated yields in plots in 1941 and 1942 (relatively infertile soil)	+0.68
Estimated yields in plots in 1942 and 1943 (relatively infertile soil)	+0.89
Estimated yields in plots (fertile soil) and estimated yields in plots (relatively infertile soil) in 1941	+0.18
Estimated yields in plots (fertile soil) and estimated yields in plots (relatively infertile soil) in 1942	+0.90
Estimated yields in plots (fertile soil) and estimated yields in plots (relatively infertile soil) in 1943	+0.74
Degree of grazing plots in 1941 and degree of grazing plots in 1942	+0.93
Degree of grazing plots in 1942 and degree of grazing plots in 1943	+0.85
Estimated yields of plots (relatively infertile soil) and degree of grazing in 1941	−0.53
Estimated yields of plots (relatively infertile soil) and degree of grazing in 1942	−0.82
Estimated yields of plots (relatively infertile soil) and degree of grazing in 1943	−0.79

*5% level of significance for 25 pairs of comparisons = 0.40.
1% level of significance for 25 pairs of comparisons = 0.51.

reestablish differences between most selections as marked as those noted in space-planted nursery rows or in the first year in small plots. Myers and Sprague (4) grew 13 selections and 2 commercial seed lots of Kentucky bluegrass in replicated field plots. Their results indicated that there was no noticeable tendency for differences among strains to disappear in the third year as compared with the first. Results in the studies which are herein presented show that eight of the selections were superior to the commercial lot in the first and second year, but that only one of this group was superior in the third year on both soil types.

The results indicate that strains of bluegrass which are significantly more productive than commercial bluegrass can be isolated by breeding procedures, but their practical value when grown under soil conditions such as exist in areas in which these investigations have been conducted appears uncertain. In results thus far superior types obtained from nursery selections have proved to be disappointing in producing increased and maintained yields of forage in pasture trials, differences between selected and commercial lots being small and of doubtful practical value. Further investigations, under conditions in which moisture and particularly fertility are less limiting

are required before the practical value of different strains for use as pasturage can be accurately ascertained.

It is recognized that commercial bluegrass might be highly variable, depending upon the locality where harvested, and that several lots would be desirable to provide adequate checks. In the experiments of Myers and Garber (3) no commercial lot was used. However, their highest yielding strain produced only 1.64 times the yield of the lowest producing type in the third year though presumably not all of the 81 lots tested were selected for high productivity. Assuming a hypothetical yield for commercial bluegrass based upon the average of the low and high strains, only 3 of the 81 lots tested by them would have been significantly superior to a commercial lot and then only slightly so. It is recognized, however, that in their studies plots of bluegrass with white clover were harvested and that white clover growth might tend to equalize differences in grass strains when grown with them. Data given do not indicate that lower yielding plots contained proportionately more white clover than higher yielding ones. Based upon these arguments their results were thus similar to those obtained in the present experiments.

Data which are given in Table 5 show that there was poor agreement in yields among the selections the first and second harvest years but good agreement in yields of the selections in the second and third and third and fourth harvest years. The data of Hayes and Thomas (1) likewise indicate good agreement in yields between 1941 (second year) and 1942 (third year) of clonal plots of bluegrass established in the fall of 1939.

Differences noted in the behavior of the selections of bluegrass between the first and second harvest years were probably due, in part at least, to changes or differences in the nutrient content of the soil, to variation in seasonal conditions, and to inherent differences among the selections themselves occasioned by the length of time required after seeding to attain maximum production. Additional information is needed in assessing the significance and relative importance of these and other factors which may affect the growth and general behavior of selections of bluegrass when grown in plot trials.

SUMMARY AND CONCLUSIONS

Approximately 11,800 plants of 490 progenies of Kentucky bluegrass, representing 353 collections made in Wisconsin, 92 in other states, and 45 in foreign countries, were grown in space-planted rows in breeding nurseries at Madison, Wis., during the period of 1936–39, inclusive. Seventy-four of the better appearing progenies were selected as being of sufficient promise to warrant further evaluation and were grown in small plot trials.

When grown in small plots there was a marked tendency for original differences between most strains to become less pronounced as seedings increased in age. Based upon estimated yields the first year, 24 of the selections grown in relatively fertile Carrington silt loam soil and 8 of those grown in relatively infertile Miami silt loam soil were more productive than commercial bluegrass. The second season nine

of the selections grown in relatively fertile soil and two of those grown in relatively infertile soil were more productive than commercial bluegrass. The third year, only three selections grown in relatively fertile soil and two selections grown in relatively infertile soil were more productive than commercial bluegrass. One of the 74 selections was superior to commercial bluegrass in all three years on both soil types.

Strains of bluegrass significantly more productive than commercial bluegrass were isolated, but the practical value of these strains must be determined in further studies.

There was good agreement between results based on actual and estimated yields in both the first and second harvest years.

There was little or no relation between yields of the same selections during the first and second harvest years when grown in relatively fertile soil. There was a good relation between the yields of the same selections during the second, third, and fourth harvest years when grown in both relatively fertile and infertile soils.

There was little or no relation between estimated yields of the selections grown in space-planted nursery rows and yields in mass seedings.

While there was some indication in the data that taller growing, more productive selections were better competitors with white clover than shorter growing less productive ones, the correlations obtained when comparisons were made between yields and competitive ability with white clover were so low as to be of little value for purposes of prediction.

Results which are presented indicate that growth and appearance of spaced plants cannot be safely used to predict the yields of the same strains in mass seedings.

The principal diseases occurring on Kentucky bluegrass were leaf spot, *Helminthosporium vagans* Drechl., leaf rust, *Puccinia rubigo-vera* (D.C.) Wint., and *P. Poae-sudeticae* West., and mildew, *Erysiphe graminis* D.C. In addition, some genotypes were affected by stripe smut, *Ustilago striaeformis* (West.) Niess. Development of disease was greater among plants in space-planted nursery rows than among those in mass seedings. There was little or no relation between yields of the selections grown in mass seedings and disease reaction.

LITERATURE CITED

1. HAYES, H. K., and THOMAS, H. L. A selection experiment with Kentucky bluegrass. Jour. Amer. Soc. Agron., 36:1001–1002. 1944.
2. NILSSON-LEISSNER, G., and NILSSON, F. Herbage plant breeding in Sweden. Imp. Agr. Bur. Joint Pub., 3:15–51. 1940.
3. MYERS, W. M., and GARBER, R. J. The evaluation of individual plants of pasture grasses in association with white clover. Jour. Amer. Soc. Agron., 34:7–15. 1942.
4. ————, and SPRAGUE, V. G. Evaluation of strains of Kentucky bluegrass in association with white clover. Jour. Amer. Soc. Agron., 36:1003. 1944.
5. TYSDAL, H. M., and KIESSELBACH, T. A. Alfalfa nursery techniques. Jour. Amer. Soc. Agron., 31:83–98. 1939.
6. WEIHING, R. M., and ROBERTSON, D. W. Forage yields of five varieties of alfalfa grown in nursery rows and field plots. Jour. Amer. Soc. Agron., 33:156–163. 1941.

COPPER STUDIES WITH OREGON SOILS[1]

L. K. WOOD[2]

EVIDENCE that copper is a nutritive element for plant growth has been presented conclusively by investigators in various parts of the world, but field response to copper additions has been limited to small areas. In the United States, some of the organic soils of the Florida Everglades and others are known to respond to copper fertilizers, while in Australia Wild and Teakle (6)[3] have obtained yield increases where small quantities of bluestone have been applied to mineral soils. Holmes (2) has studied the copper content of various United States soils.

It is to be regretted that in most cases reported, copper has been added to the soil in the form of copper sulfate with an attempt made to eliminate the sulfur effects by blanket sulfur additions or with a sulfur carrier. While the increases in yield obtained are generally ascribed to the copper, elimination of the sulfur effect may not be conclusive. Copper is added in such small quantities that the economy of using the sulfate rather than the chloride form in experimental work may not be justified, although in field applications the sulfate form is preferable.

The use of copper as a fertilizing element has been studied in Oregon and was based on response shown by various cane fruit crops grown on different soils of the state. While it is an accepted fact that some Oregon soils respond to sulfur applications, the practice has been to add copper in the form of copper sulfate at a rate of 20 to 40 pounds per acre.

As designed by Powers (4) of the Oregon station, the check plot rows include a $CaSO_4$, a sulfur, and untreated rows. Minor element plots are blanketed with 500 pounds per acre of 4–16–8 fertilizer. Table 1 contains data from the copper-treated rows, the sulfur row, the calcium sulfate row, and the nearest check rows in each case. The response from three different experimental berry farms is neither uniform nor consistent, but the increase in crop yield from the use of copper sulfate is seen to be more consistent the year of addition than the following year. Wide differences noted in yields of the check plot rows likely can be explained on the basis of soil differences. Sulfur, added at the rate of 30 pounds per acre, is not consistent in its response and is being studied further. In order to investigate the basis of a possible response to copper sulfate additions and also the cause for erratic responses, the following experiments were carried out during the year of 1942–43.

In considering the causes likely to account for an erratic response the availability or solubility of the added copper, in addition to the native copper content, and the presence of added sulfur were investi-

---

[1]Published as Technical Paper Number 451 with the approval of the Director of the Oregon Agricultural Experiment Station, Oregon State College, Corvallis, Ore., as a contribution of the Soils Department. Received for publication November 29, 1944.

[2]Assistant Soil Scientist.

[3]Figures in parenthesis refer to "Literature Cited", p. 291.

TABLE 1.—*Yield of cane fruits as affected by additions of copper sulfate, calcium sulfate, and sulfur compared to the nearest untreated row.**

Plot No.	Treatment and pounds per acre	Yield, tons per acre					
		1939	1940	1941	1942	1943	4-year av.
	Ede Blackcaps, Lacomb, Ore., Olympic Clay Loam						
14	Check	—	0.82	0.51	0.58	1.10	0.75
15	$CuSO_4$, 40†	—	1.06	0.46	1.04	1.30	0.96
21	Check	—	0.73	0.53	0.94	0.61	0.68
22	S, 40	—	0.75	0.45	0.99	0.65	0.71
23	$CaSO_4$, 40	—	0.73	0.57	0.78	0.59	0.68
	Fritz Raspberries, Gresham, Ore., Powell Silt Loam						
4	Check	3.07	2.68	1.81	2.97	1.04§	2.63
5	$CuSO_4$, 30‡	3.20	2.70	1.56	2.73	1.14	2.55
10	Check	3.22	3.18	2.21	3.34	1.62	2.99
12	S, 30	3.11	3.16	2.14	3.12	2.00	2.88
22	$CaSO_4$, 30	3.15	3.09	1.98	3.43	1.50	2.91
	Jackson Boysenberries, Gresham, Ore., Powell Silt Loam						
32	$Cu SO_4$, 30†	—	7.12	4.95	2.81	3.24	4.53
34	Check	—	6.16	4.41	2.62	2.91	4.02
42	Check	—	5.83	4.60	4.29	3.47	4.55
44	S, 30	—	7.21	4.54	3.54	3.27	4.64
46	$CaSO_4$, 30	—	—	2.38	2.43	2.40	2.40

*Data courtesy of W. L. Powers.
†Broadcast 40 pounds per acre in 1940, 1942, and 1943.
‡Broadcast 30 pounds per acre in 1939, 1942, and 1943.
§Not included in average as area quarantined after harvest of only part of crop.

gated. To obtain field response from additions of a fertilizer element, a deficiency must be eliminated by the addition either supplying the limiting element or by increasing the availability of the native materials present through some secondary cause such as changes in soil reaction or pH. These considerations suggested two possible lines of attack. The first was an availability study of the native copper supplies of the soils suspected of giving a response, even though erratic, based on solubility in various extractants. The second was a fixation study based on the apparent beneficial effect noted chiefly the year of addition.

LABORATORY STUDIES OF SOIL COPPER SOLUBILITY

ACID EXTRACTION STUDY

Previous to attempting research on this problem, a method for the laboratory determination of copper in plant and soil materials was adapted to the soils studied. The method of copper determination as outlined by Sherman and McHargue (5) which utilizes the highly colored solution produced by copper in the presence of sodium-diethyl dithio carbamate in alkaline solution was used, the color intensities being read with a Klett-Summerson colorimeter. The sensitivity of this reagent is such that precautions to guarantee copper-free reagents must be taken.

Four surface soils which had indicated an erratic response to

copper sulfate fertilization were used in these studies.[4] They include the Olympic silty clay loam, a brown soil from the Ede farm, Lacomb, Ore.; Hammond sandy soil, which contains considerable organic matter, from the McConnell poultry farm, Camp Clatsop, Ore.; Powell silt loam, a soil from the Fritz farm in Gresham, Ore.; and Labish peat, an organic soil taken from the Lake Labish area near Salem, Ore.

One hundred and fifty pound samples were collected from the three mineral soil areas and 75 to 100 pounds from the peat area. These soils were brought to the laboratory, air dried, thoroughly mixed, and screened before use. Approximately 1 kilogram of each soil was placed in containers convenient for storage in the laboratory and small samples were removed from this master sample as needed for analysis.

A preliminary acid extraction study was made to determine the solubility of soil copper in boiling nitric acid of different strengths. Five-gram samples of each soil were subjected to successive extraction with neutral normal ammonium acetate, boiling normal, boiling 5 normal, and boiling 10 normal nitric acid. The boiling operation was carried out for a period of 10 minutes with cover glasses used to prevent excessive acid concentration changes. After the individual extractions were made, the samples were filtered, washed, and treated with the next strength extractant. Filtrates were taken to dryness and hydrochloric and nitric acids added and evaporated to dryness again. This operation removed organic matter in all cases except with the peat soil which yielded to repeated treatments with the same solutions. The extracted materials were taken up with dilute HCl and made up to volume. The copper content was then determined in an aliquot of this solution. In the case of the ammonium acetate leachate (exchangeable copper) all of the extract from a 5-gram sample was used to get a satisfactory Klett reading because in all cases the exchangeable copper was found to be less than 1 p.p.m. With the acid extractions one-tenth of the total volume was found to give convenient readings. The results of this study are found in Table 2.

TABLE 2.—*Copper extracted from four soils using different strength extractants.*

Soils	NH_4 acetate, exch. Cu, p.p.m.	N/1 HNO_3, p.p.m.	5 N HNO_3, p.p.m.	10 N NHO_3, p.p.m.	Total copper extracted, p.p.m.
Hammond sand	0.30	10.0	10.0	3.4	23.7
Olympic silty clay loam	0.40	27.0	19.4	10.0	57.0
Powell silt loam	0.16	19.0	8.6	2.4	30.2
Labish peat	0.60	8.0	10.0	5.2	23.8

The total copper content of these soils was determined by digestion with a mixture of perchloric and hydrofluoric acids with subsequent color development as described above. The results are found in Table 3.

[4]Unpublished data of W. L. Powers.

TABLE 3.—*Parts per million of acid extractable copper and total copper and the percentage of acid-extractable copper.*

Soil	Copper extracted by successive HNO_3 extraction, p.p.m.	Total copper, p.p.m.	Difference, p.p.m.	Percentage copper extractable by acid
Hammond sand.......	23.7	68.0	44.3	34.8
Olympic silty clay loam	57.00	174.0	117.0	32.7
Powell silt loam.......	30.16	78.0	47.8	40.4
Labish peat..........	23.8	60.0	36.2	39.7

The solubility of soil copper to the extracting technics used varied with the different soils and the net quantity extractable became smaller with increasing strength of acid used. With the successive acid treatments the soils release about 40% of their total copper, 60% remaining insoluble. The copper in exchangeable form probably available for plant use is very small in amount, ranging from 0.16 to 0.60 p.p.m. Since none of the soils are low enough in available copper to cause plants to exhibit deficiency symptoms when grown in the soil in the greenhouse, it is assumed that a supply of 0.1 to 1 p.p.m. of exchangeable copper is sufficient for normal growth, provided that quantity is maintained. If such is the case, the ability of a soil to provide a working margin of 0.5 p.p.m. of copper available to plant roots should indicate roughly the boundary between response and no response to copper additions. As shown later, copper extracted by boiling normal nitric acid represents that copper which, through weathering and other processes, may become available for plant use as the exchangeable supply is lowered. If a field response to added copper is obtained, it may be because the exchangeable or available form has either been depleted by crop absorption or because of a failure of the slowly available form (acid soluble) to become available to the roots. Such a failure could be due to an extremely low native supply. From the above data it will be seen that the soil with the highest total copper is the soil able to deliver the largest quantity of copper to a boiling acid treatment, yet sufficiently large quantities of copper exist in the normal nitric acid extract of all the soils studied to offset deficiencies for many years, provided an equilibrium exists between immediately available and slowly available forms. This equilibrium is shown to exist in the fixation study reported later in this paper.

It is of interest to note that the mineral soil giving the most consistent field response to copper additions, the Olympic soil, is also the soil which has the highest exchangeable, slowly available, and total copper contents. Since additions of copper compounds to this soil tend to cause increased fruit production, the other soils should show at least equally great responses when copper is added to them. Such is not the case to date, leading one to suspect that the response obtained is not due to the added copper but rather to some other factor or factors. The possibility of sulfur being the deficient element

has not been entirely removed. Soil and plant differences, improvement in flora due to partial sterilization, or the addition of a bactericidal substance or some combination of these factors should also be considered.

The wide variation in available copper exhibited by these soils does not suggest an explanation as to why copper additions should give an increased crop growth. Consideration of the supplying power as measured by extractability also fails to indicate a solution to the problem. It is likely that the copper in the peat and sand soils exists chiefly in organic froms, yet as with the mineral soils, the copper is largely insoluble in the acid used. The variation from 60 to 174 p.p.m. of total copper passing from the organic soil to the mineral soils is not unique, but the presence of 174 p.p.m. of copper is considerably higher than figures previously published on total copper content of soils. This soil is the Olympic silty clay loam, a brown soil developed from basaltic rocks.

FIXATION STUDY

The solubility study fails to suggest reasons for the erratic response to copper additions. In order to investigate the cause for observed increases the year copper additions are made with no pronounced carry-over of the fertilizer effects the second year, the possibilty of copper fixation in a form not extracted by neutral normal ammonium acetate was investigated. In this study the four soils were subjected to two different laboratory treatments and received copper additions at six different rates.

Duplicate 100-gram samples of each soil were treated with 0, 5, 10, 40, 80, and 160 p.p.m. of copper as copper sulfate. The soils were then alternately moistened with copper-free water and dried in an oven at 105° C 10 consecutive times. The soils were then subjected to extraction with the neutral acetate and boiling 1 and 5 normal nitric acid. Copper was determined in the extracts and all added copper not removed with the acetate leach was considered fixed.

Additional duplicate samples were stored in a moist condition (30% water in the mineral soils; 50% water in the peat soil) at room temperature for 100 days. At the end of this period 20 grams of soil from each sample were removed, allowed to become air dry, and the extractions outlined above were carried out. At the end of an additional 100 days this operation was repeated.

Data obtained from the alternate wetting and drying operations and from the moist storage at two 100-day intervals are shown in Table 4.

ALTERNATE WETTING AND DRYING

Comparing the original untreated soils with the soils receiving the heat treatment but no addition of copper, alternate wetting and drying of the mineral soils resulted in an increase of the available copper, whereas the organic soil resulted in a decrease. The increases are rather large, particularly with the Powell and Olympic soils. This release of insoluble copper to soluble forms correlates with the results obtained by Bray and DeTurk with potassium (1). These investiga-

tors obtained release of potassium from insoluble forms by a similar heat treatment. The native copper content of these soils is much greater than that of the Hammond or the organic soil and likely facilitates the release of copper. The drastic alternate wetting and drying treatment probably encouraged organic combination of copper which would account for increased quantities of insoluble copper in these soils.

The exchangeable copper of the uncoppered soils decreases during the wetting and drying operation with a resultant increase in acid insoluble forms. The addition of copper has resulted in fixation in all cases, the combined acid extractions removing only part of the added copper. Thus, fixation beyond extractability in boiling 5 normal nitric acid accounts for a large portion of the added copper. Fixation within the arbitrary solubility limits of boiling normal and boiling 5 normal nitric acid varies for the different soils and the different additions from 20 to 100% of the added copper. With the Hammond sand an average of all treatments indicates 75% of the added copper is extractable by the acid treatment; Olympic soil, 15%; Powell soil, 70%; and the organic peat, 65%. The Olympic soil, which contains the largest quantity of native copper, and which also is the soil that apparently responds more consistently to copper additions in the field, retains added copper in insoluble forms to a greater degree than the other soils. This high average retention percentage is shown by the failure to extract any of the 10 p.p.m. addition. However, excluding this one addition from the average, a high retention for this soil is obtained, namely, 37% of the addition. Such a high retention of added soluble copper casts light on the problem of erratic response by this soil.

MOIST STORAGE

Data from samples stored in a moist condition are available for two periods of 100 and 200 days, respectively. Wide variations in the amounts of extractable copper in the different forms at the two sampling periods suggest that the copper exists in forms which are in equilibrium with each other. The results are not sufficiently consistent with size of addition to indicate a stable equilibrium, yet in general, the more copper added as copper sulfate, the more fixation occurs in all forms measured.

With the uncoppered check soils less copper was found to be extractable after being moist 100 days, the quantity decreasing with longer storage. Where copper is added the equilibrium is unbalanced and absorption in the different soils and with the different rates of treatment varies from instances where no copper is left exchangeable to where some 4 p.p.m. are exchangeable. The same is true in degree in regard to the acid-soluble classes. Also, significant rearrangement of the equilibrium occurs in the second 100-day storage period and copper is shifted in solubility from one form to another. Wood and DeTurk (7) have described this shifting equilibrium in regard to soil potassium in Illinois soils, while Jamison (3) has described copper fixation in Florida soils.

TABLE 4.—*Parts per million of exchangeable normal HNO_3 and 5 normal HNO_3 soluble copper extracted from untreated soils receiving no copper and from soils receiving copper additions after 10 successive wettings and dryings at 105° C and the copper extracted by these reagents after storage at room temperature in a moist condition for two consecutive periods of 100 days.*

Soil and p.p.m. of copper added	Exchangeable			N HNO_3			5N HNO_3			Total extracted		
	Dry, p.p.m.†	Wet, p.p.m.†		Dry, p.p.m.	Wet, p.p.m.		Dry, p.p.m.	Wet, p.p.m.		Dry, p.p.m.	Wet, p.p.m.	
		1st period	2nd period		1st period	2nd period		1st period	2nd period		1st period	2nd period
Hammond sand:												
Untreated......		0.3			10			10			20.3	
0............	0.70	0.16	0.72	4.40	9.80	10.0	2.40	1.72	5.2	7.50	11.68	15.92
5............	0.86	0.18	0.96	5.50	12.60	9.0	4.00	2.20	5.8	10.36	14.98	15.76
10............	0.98	0.16	1.00	11.40	12.20	12.0	5.60	1.80	5.8	17.98	14.16	18.80
40............	0.70	0.16	1.76	27.80	28.00	30.8	9.00	9.00	9.0	37.50	37.16	41.56
80............	0.77	0.32	1.80	50.00	40.40	52.5	14.80	9.20	11.6	65.57	49.92	65.90
160............	1.98	0.46	2.66	92.00	102.00	83.0	20.60	14.20	11.5	114.58	116.68	97.16
Olympic clay loam:												
Untreated......		0.4			27			19.4			46.8	
0............	1.20	0.18	1.33	28.40	24.20	18.0	18.00	20.00	28.0	46.60	44.38	47.33
5............	1.51	0.08	1.32	28.40	27.80	18.04	17.60	23.60	32.0	47.59	51.48	51.36
10............	0.80	0.46	1.32	24.60	32.20	20.16	13.20	26.00	33.4	38.60	58.66	54.88
40............	1.20	0.66	1.56	47.00	50.00	40.30	21.20	32.00	39.8	69.40	82.66	81.46
80............	2.08	0.54	1.84	46.40	64.00	66.0	24.00	22.60	39.8	72.48	87.14	106.64
160............	5.39	4.20	2.04	72.40	94.50	114.0	33.40	31.00	34.0	111.19	129.70	150.04

Powell silt loam:												
Untreated		0.16			19			8.6			27.76	
0	1.04	0.46	0.58	13.00	14.20	9.0	8.00	9.00	14.0	22.04	23.46	23.58
5	1.04	1.20	0.62	15.60	21.20	11.8	9.20	11.20	15.0	25.84	33.60	27.42
10	1.14	0.86	0.57	20.00	23.00	19.0	9.90	9.20	19.0	31.04	33.06	38.57
40	1.90	1.10	2.06	35.00	40.00	30.0	11.00	10.00	20.0	47.90	51.10	52.06
80	2.08	1.50	3.00	52.20	64.00	59.0	14.00	11.40	24.0	68.28	76.90	86.00
160	5.02	3.96	2.84	93.20	120.00	65.0	23.60	13.00	17.6	121.82	136.96	85.44
Labish peat:												
Untreated		0.60			8			10			18.60	
0	0.42	0.00	1.16	0.34	5.60	3.8	5.60	8.00	7.2	6.36	13.60	12.16
5	0.50	0.00	1.18	4.00	6.60	4.8	6.20	9.40	7.2	10.70	16.00	13.18
10	1.18	0.00	1.20	4.00	9.00	7.0	6.80	10.40	7.2	11.98	19.40	15.40
40	1.18	0.00	1.45	17.00	13.20	15.8	15.80	11.20	14.0	32.98	24.40	31.25
80	1.60	0.00	1.58	25.00	30.00	33.6	25.40	24.00	22.4	52.00	54.00	57.58
160	1.62	0.00	1.76	57.00	48.00	52.0	39.00	32.00	27.2	97.62	80.00	80.96

*Wet with copper-free distilled water and dried in an oven at 105° C 10 consecutive times before determination of fate of copper.
†Soils thoroughly mixed with copper addition in solution and stored moist for two 100-day periods.

Comparing the results of the two types of treatment—alternate wetting and drying and moist storage—fixation in acid-soluble forms is greater where stored moist than with the drying technic, indicating a more tenacious or total fixation with the latter type of treatment.

GREENHOUSE STUDIES

A greenhouse study with the four soils planted to oats with copper additions at two rates, 10 and 50 pounds of copper per acre, was conducted. In none of the trials was copper found to increase plant growth.

In order to correlate the degree of fixation with plant growth, small duplicate pots containing less than 50 grams of the soils which had fixed copper as above described were planted to Bountiful beans. No fertilization was given the pots at first, but later it was found necessary to give small additions of a 3–10–10 ratio fertilizer in order to keep the plants healthy. Germination appeared to be slow, but there was no correlation between duplicate pots or soil treatment. The small size of the pots naturally made transpiration a problem when the plants reached full leaf, however, no serious wilting occurred. The plants grew to maturity and produced bean pods even though the soils had received copper additions ranging from none to 160 p.p.m. This indicates fixed copper was not available to the bean plant in toxic amounts. Since there was no relationship between response and treatment and since uptake of copper was not important in this study, no chemical analyses were made or yield data taken.

SUMMARY AND CONCLUSIONS

Experiments are described which were made on four typical Oregon soil types to study the causes of erratic response to copper sulfate fertilization of cane fruits. These experiments included a solubility study using extractants of increasing strength; a fixation study in which amounts of copper as copper sulfate up to 160 p.p.m. were added to the soils; greenhouse work using low-copper and high-copper applications; and an availability study of fixed copper using beans.

The following conclusions appear to be justified:

1. An acid extraction of soils using boiling 1 and 5 normal nitric acid established arbitrary boundaries with copper solubility that were reproducible.
2. Acid extraction of the four soils studied indicated that, although the soils differed in total native copper contents and in the amounts extractable by neutral normal ammonium acetate and by different strength boiling nitric acid, the quantity of copper available was sufficient for plant growth.
3. Soil copper exists in an equilibrium between available, slowly available, and extremely slowly available forms. These forms contain sufficient copper for plant needs, hence yield increases may not be obtained from soluble copper additions to the soils studied.
4. Copper fixation absorbed most of the addition whether the soil was subjected to an alternate wetting and drying or to a moist storage.
5. Oat plants gave little or no response to copper additions.

6. Fixed copper is not available to growing bean plants.

7. None of the four soils studied responded definitely to copper additions by increased growth and it is doubtful that use of copper supplements in these soils would prove economical.

8. Erratic response obtained in the field appears to be due to factors other than a deficiency of copper in available forms in the soils studied.

LITERATURE CITED

1. BRAY, R. H., and DETURK, E. E. The release of potassium from nonreplaceable forms in Illinois soils. Soil Sci. Soc. Amer. Proc., 3:101–106. 1939.
2. HOLMES, R. S. Coppper and zinc in United States soils. Soil Sci., 56:359–370. 1943.
3. JAMISON, VERNON C. Absorption and fixation of copper in some sandy soils of central Florida. Soil Sci., 53:287–297. 1942.
4. POWERS, W. L. Progress report, on studies of the causes of malnutrition in cane fruits. Ore. Agr. Exp. Sta. August, 1942.
5. SHERMAN, G. D., and MCHARGUE, J. S. Methods for determination of copper and zinc in soil. Jour. Assoc. Off. Agr. Chem., 25:510–515. 1942.
6. WILD, A. S., and TEAKLE, L. J. H. Experiments with micro-elements for the growth of crops in western Australia. Jour. Dept. Agr. Western Australia, 19:71–78. 1942.
7. WOOD, L. K., and DETURK, E. E. The release of fixed potassium to replaceable or water-soluble forms. Soil Sci. Soc. Amer. Proc., 7:148–153. 1943.

AMOUNTS OF FERTILIZER ELEMENTS REMOVED BY PEAS AT THREE STAGES OF GROWTH[1]

BENJAMIN WOLF[2]

A KNOWLEDGE of the amounts of nutrients removed by a crop, the rate of such removal, and the soil's ability to meet such demand is of great practical importance to the agronomist. The results reported in this paper are an attempt to obtain such knowledge for a crop of canning peas (variety Thomas Laxton) grown under South Jersey conditions.

METHODS

Two fields were selected in 1943 for the purpose of this study. The fields, consisting of Sassafras loam soil, varied considerably in previous crop yields. Peas were planted in field No. 7 on April 15 and in field No. 92 on April 17. They had been fertilized before planting with approximately 1,500 pounds per acre of a 4-12-8 fertilizer, broadcast and disked into the surface. Abundant moisture and favorable temperatures aided in producing large crops. Harvested on June 17 and 19, field No. 7 produced 4,300 pounds and field No. 98, 2,400 pounds of shelled peas, respectively.

Five crop samples consisting of 2 sq. ft. each of growing peas were selected from each field approximately 35, 49, and 63 days after planting. Nearly all vines were blossoming and a number of small pods had formed at the end of the 49-day period. The sampling at 63 days after planting was just prior to harvesting.

In all cases, the plants were carefully dug from the soil in an effort to remove the majority of the roots. The roots were later washed free of soil. The plants of the last sampling were divided into roots, vines, pods, and seeds.

Samples of the A_p layer of soil were also collected at each sampling date.

Portions of the plant samples were dried and ground to a fine powder. These samples were analyzed for total N, P_2O_5, and K_2O by rapid chemical tests (1).[3] Samples of the fresh tissue (stems) and soil were analyzed for soluble phosphorus and potassium (2). Nitrate N in both plant and soil was determined by the Brucine reaction (3).

RESULTS

The results of the various tests are given in Tables 1 and 4. The amounts of dry matter produced and the nutrients removed during three different periods of growth are given in Table 1.

It was quite apparent from the results in Table 1 that the amounts of nutrients removed bore a direct relationship to the yields of the crop. The 4,300 pounds of (fresh weight) shelled peas in field No. 7 removed 81 pounds of N, 37 pounds of P_2O_5, and 70 pounds of K_2O as compared to 45 pounds of N, 20 pounds of P_2O_5, and 37 pounds of K_2O for the 2,400 pounds of shelled peas in field No. 98. However, the amounts of nutrients removed by the crop to produce a hundred weight of shelled peas was quite similar (Table 2).

Analyses of various portions of the pea plants of the last sampling were used to calculate the amount of nutrients removed from an acre to form various portions of the plant. The results are given in Table 3.

[1]Contribution from the G. L. F. Seabrook Farms Raw Products Research Division, Seabrook Farms, Bridgeton, N. J. Received for publication December 4, 1944.

[2]Soil Chemist.

[3]Figures in parenthesis refer to "Literature Cited", p. 296.

On May 27, 1944, some representative plants were pulled for weight determinations, with the results shown below:

	Number of plants	Green weight, grams	Average green weight per plant, grams
No sulfur.....	24	56	2.3
Sulfur added..	14	341	24.4

The visual differences were very striking in the young plants but almost disappeared as the plants approached maturity, except that the plants without sulfur were smaller.

The cotton was picked September 5 and October 4, 1944. The results, given in Table 1, indicate that magnesium was not a factor in this experiment since there was not a significant difference between treatments 3 and 4. Treatments 2 and 3 are identical except 3 contains sulfur. That sulfur treatment gave a highly significant increase in yield of 43% over the no-sulfur treatment. Treatments 4 and 5, which contained sulfur, gave highly significant increases in yields over treatment 2. The fertilizer in treatment 1 was placed directly under the cotton. This placement was used in only one case, but it was significantly better than no-sulfur treatment 2, which was placed in bands. Just why that is true is not known, but it may be possible that the small amounts of sulfur carried as an impurity in the no-sulfur fertilizer might be nore effective when in close contact with the plant. Or, since it was dry in the early part of the growing season, the materials placed where the moisture was more abundant may have been more effective. Even so, treatments 3 and 5, which contained sulfur, are significantly better than treatment 1. In view of these facts it is evident that sulfur in the fertilizer had a pronounced effect on the yields of the upland cotton.

TABLE 1.—*Mean yields in pounds of upland seed cotton per plot for 4-8-4 fertilizer mixtures with and without sulfur and magnesium, applied as indicated.*

Treatment No.	Treatment	Placement	Mean, pounds per plot
1	No sulfur	Under	13.8
2	No sulfur	Bands	11.4
3	Sulfur	Bands	16.3
4	Sulfur and magnesium	Bands	15.2
5	Sulfur and magnesium	Bands and plowed under	15.9

The least significant difference at 5% level = 2.03
The least significant difference at 1% level = 2.85

EXPERIMENT 2

A second experiment, almost identical to experiment 1, was set up at the same time on the Experiment Station Farm at Gainesville on Norfolk fine sand. In this case Seabrook 12B2 sea island cotton was planted.

The early growth responses in size and color to the sulfur treatment were similar to those secured on the upland cotton. Fig. 2 shows this difference.

On May 26, 1944 representative plants from the sulfur and no-

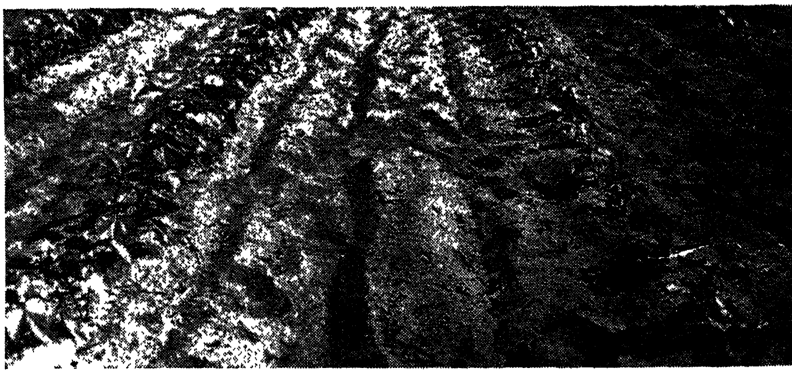

FIG. 2.—Sea Island cotton in experiment 2, May 20, 1944, 43 days after planting *Left*, with sulfur; *right*, without sulfur.

sulfur treatments were secured for weight determinations with the results tabulated below:

	Number of plants	Green weight, grams	Average green weight per plant, grams
No sulfur.....	13	97.0	7.5
Sulfur........	10	404.5	40.5

The appearance of the sea island cotton and the above results suggest that the sulfur was quite important in this case also. The cotton was picked October 6 and October 26, 1944; however, that year all of the sea island cotton was poor. The season was unfavorable and boll weevils did much damage so that yields were low and erratic and for this reason, the differences in yields were not significant and the results will not be given.

EXPERIMENT 3

The third experiment was conducted near Madison, Fla., about 100 miles northwest of Gainesville. The soil is a Norfolk loamy fine sand. It had been in cultivation for many years and was in a run down condition. The soil was known to respond to potash fertilization.

In this experiment it was desired to secure information on rates of potash for the growth of cotton as well as the effect of sulfur and magnesium above the amount carried in the fertilizer. Materials were not available to mix a fertilizer relatively free of sulfates, so it was decided to try to arrive at the difference between sulfur and magnesium by an indirect means. It was thought that a rough differentiation between them could be secured by subtracting increases in yields due to sulfur from those of magnesium sulfate containing an equivalent amount of sulfur. A commercial 3–8–8 fertilizer was applied at the rate of 375 pounds per acre as a basic treatment on all plots. The manufacturer reported that it was made from muriate, manure salts, superphosphate, and mostly inorganic nitrogen. A sample of the same brand of fertilizer was analyzed and contained

14.5% water-soluble SO_3. The magnesium and sulfur treatments were as follows: (1) Commercial fertilizer only; (2) commercial fertilizer plus magnesium sulfate ($MgSO_4 \cdot 7H_2O$) at the rate of 100 pounds per acre mixed with the commercial fertilizer; and (3) commercial fertilizer to which 15 pounds per acre of dusting sulfur was added. It was intended that the dusting sulfur be used at a rate equivalent to the sulfur content of the magnesium sulfate, but by oversight no allowance was made for the 7 to 10% inert material carried by the dusting sulfur, thus the sulfur rate was a little lower in the dusting sulfur groups than in the magnesium sulfate groups.

The above sulfur-magnesium treatments were used in connection with applications of potash (K_2O) of 30, 45, 67, 100, 150, and 225 pounds per acre.

The fertilizers were applied in the row about 1 week before planting. Potash rates above 30 pounds per acre were applied as muriate as a side-dressing at the early square stage. Sodium nitrate was applied at the rate of 80 pounds per acre at chopping time to all plots.

There were six replications of each of the six potash rates, making a total of 36 blocks containing the randomized sulfur-magnesium comparisons. The plots, 7×100 feet, contained two rows.

Stoneville 2B upland cotton was planted April 7, and was picked August 28 and September 13, 1944.

Table 2 indicates that potash had a pronounced effect on the yield of the cotton; however, this paper is not concerned with potash responses, since different rates of potash did not give a differential response to sulfur or magnesium sulfate (Fig. 3).

As there was no differential response to potash, the treatments were paired throughout the experiment and Student's method of statistical analysis was used. The analysis shows (Table 2) that sulfur,

TABLE 2.—*The influence on the mean yield of seed cotton in pounds per plot of upland cotton of adding 15 pounds of sulfur or 100 pounds of magnesium sulfate to a commercial 3–8–8 fertilizer applied at 375 pounds per acre at different rates of potash.*

Potash rate in pounds per acre*	Commercial 3–8–8 only	Sulfur added	Magnesium sulfate added	Magnesium sulfate over sulfur
30	4.53	6.06	6.41	—
45	6.02	7.36	7.96	—
67	8.41	9.92	10.44	—
100	11.27	12.09	12.78	—
150	13.20	14.00	14.47	—
225	13.43	15.55	15.10	—
Grand mean of 36 values	9.48	10.83	11.19	—
Mean difference	—	1.35	1.71	0.36
Standard error of mean difference	—	0.32	0.31	0.30
t values†	—	4.22	5.52	1.21

*Potash rates above 30 pounds were applied as sidedressing.
†t values to be significant at the 5% and 1% level are 2.03 and 2.72, respectively.

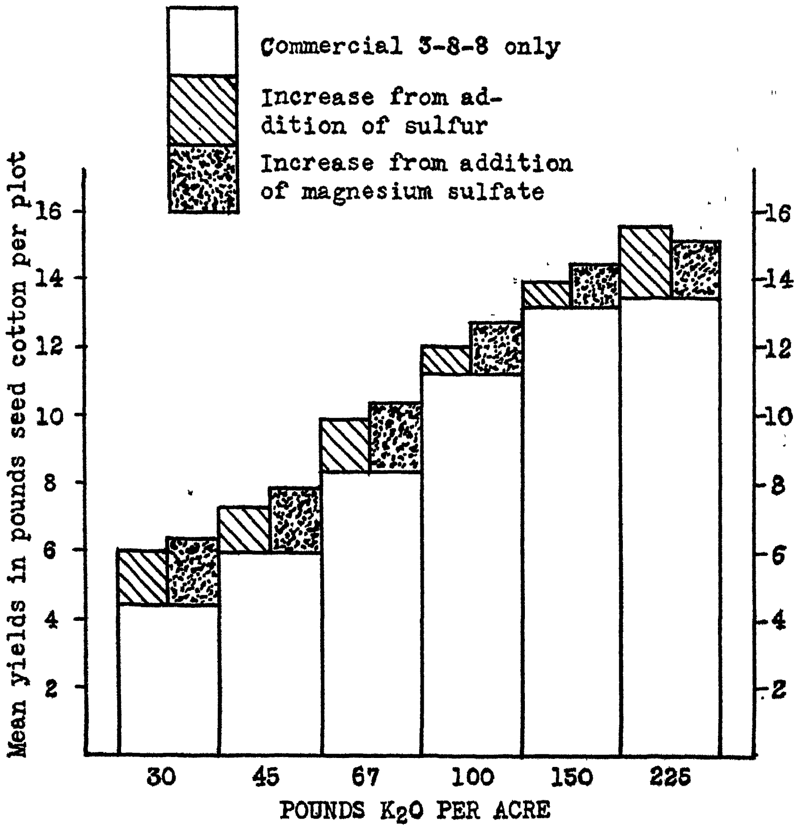

FIG. 3.—The effect of potash on the response of Stoneville 2B cotton to sulfur and magnesium sulfate.

as well as magnesium sulfate, gave highly significant increases in yields of the cotton. Magnesium sulfate gave slightly larger yields than sulfur, but the difference was not significant.

It is well known that when sulfur is applied to the soil there may be indirect effects other than sulfur nutrition. However, the fact that when almost equivalent amounts of sulfur were applied as dusting sulfur and as magnesium sulfate the yield effects were practically the same, suggests that magnesium was not a factor, and that the increase in yields on this soil was probably due to sulfur nutrition. This seems evident since 15 pounds of sulfur added above the amount carried by a commercial 3–8–8 fertilizer gave an increase in yield of 33.6%. Regardless of the increase in yield of the cotton due to higher rates of potash, the yield was further increased by the supplement of 15 pounds of sulfur.

RAINFALL

The precipitation during the growing season at Gainesville and Madison, Fla., as compared to the normal is given in Table 3. Ex-

TABLE 1.—*Amount of dry matter produced and fertilizer nutrients absorbed by an acre of peas during different periods of growth.*

Period of growth, days	Dry weight		N		P_2O_5		K_2O	
	Lbs.	% of total	Lbs.	% of total	Lbs.	% of total	Lbs.	% of total
Field No. 7								
0–35	490	9	10	12	3	8	8	11
36–49.....	1,735	32	24	30	10	27	31	44
50–63.....	3,125	59	47	58	24	65	31	45
Total...	5,350	100	81	100	37	100	70	100
Field No. 98								
0–35.....	250	8	6	13	1	5	4	11
36–49.....	1,275	37	18	40	7	35	24	65
50–63.....	1,775	55	21	47	9	60	12	24
Total...	3,300	100	45	100	17	100	60	100

TABLE 2.—*Pounds of nutrients removed by the entire crop for each hundred weight of shelled peas produced.*

Nutrients	Field No. 7	Field No. 98
N......................................	1.88	1.88
P_2O_5..................................	0.86	0.83
K_2O....................................	1.63	1.54

TABLE 3.—*Pounds of nutrients removed from an acre by various portions of pea plants.*

Nutrients	Field No. 7				Field No. 98			
	Roots	Vines	Pods	Seeds	Roots	Vines	Pods	Seeds
N................	4	35	14	28	2	19	8	16
P_2O_5...............	1	13	7	16	1	6	4	8
K_2O..............	3	43	10	14	3	17	7	10

In an effort to determine whether the fertilizer applications had been satisfactory, soluble nutrients in the soil and plants of each sampling were determined. The results are given in Table 4.

DISCUSSION

Because of favorable climatic conditions, yields were unusually high in 1943. The 4,300 pounds of shelled peas produced on field No. 7 is one of the largest yields produced in this area for a number of years. The 2,400 pounds of shelled peas produced on field No. 98 would be considered a good crop in most years. The figures for field No. 98 would more often conform to the amounts of nutrients removed by a good crop of peas.

TABLE 4.—*Soluble nutrients in soil and plants at different sampling dates.*

Nutrients	Days after planting					
	35		49		63	
	Soil*	Plant†	Soil*	Plant†	Soil*	Plant†
			Field No. 7			
NO_3+N	54	3,100	17	1,000	12	800
P_2O_5	48	2,600	37	2,200	40	2,200
K_2O	240	12,000	140	8,300	115	6,500
			Field No. 98			
NO_3+N	62	3,500	40	1,500	20	2,300
P_2O_5	20	1,300	24	1,400	24	1,400
K_2O	80	4,800	36	1,000	14	1,500

*Expressed in pounds per 2,000,000 pounds of soil.
†Expressed in p.p.m. of stem tissue on a dry-weight basis.

The amounts of nutrients removed by these two crops were rather high, with most of the nutrients being absorbed in the last few weeks of growth. From 47 to 58% of the N, 60 to 65% of the P_2O_5, and 24 to 45% of the K_2O was absorbed by the plants in the last 2 weeks of growth (Table 1).

The heavy drain of nutrients during the last 2 weeks of growth was evidently favored by two factors. First, a large proportion (approximately 55%) of the dry matter was produced in this period. Second, the formation and ripening of seeds drew heavily on both N and P_2O_5. The pods and seeds contained more N and P_2O_5 than the remainder of the plant.

This knowledge of the periodicity of nutrient removal is of utmost importance in formulating fertilizers to feed the crop. It would seem advisable to have a good supply of nutrients present in the last few weeks of growth. Not only must the supply be rather large, but it must also be readily available since large amounts of nutrients are absorbed in a short period of time. Soil and plant analysis (Table 4) would indicate that this was not the case for all fertilizer nutrients in these two fields. While P_2O_5 seemed to be rather constant for the three sampling dates, both N and K_2O contents dropped markedly as the season progressed. Wherever possible, it would seem advantageous to apply a portion of the N and K_2O several weeks after planting, perhaps in liquid form. Late applications would help insure a good supply of these nutrients when seed formation takes place. Fertilizers compounded with a portion of its N resistant to leaching and available about 5 to 7 weeks after planting would also be worthwhile.

In this area, pea yields are markedly affected by the organic matter in the soil. As a rule, yields are high where the soil organic matter is high and *vice versa*. Evidently, part of this relationship is due to the ability of the organic materials to supply nutrients at a late period of growth when the need is greatest.

The amounts taken up by a crop to produce a unit weight of peas

was rather constant despite wide differences in yield. If this relationship is universally true, it would be of great help in calculating the fertilizer nutrients removed. Such calculations could be made simply from the crop yields.

Although large amounts of nutrients were needed to produce large crops of peas, a good portion of these nutrients could be returned to the soil. The shelled peas contained less than half of the nutrients necessary to produce the crop (approximately one third of the N, two fifths of the P_2O_5, and one fourth of K_2O). Returning vines and pods to the field conserved a good portion of the fertilizer nutrients necessary to produce that crop.

Analysis of soluble nutrients in soil and plant can be valuable aids in measuring the fertility changes. The analyses of the stem were directly correlated with the soil nutrients. As has been pointed out, both nitrate N and K_2O dropped markedly in both soil and plant. In field No. 7, the nitrate N content and in field No. 98 the K_2O of both soil and plant dropped to a very low figure. Previous correlations have shown that these figures are too low for maximum production. Soil nitrate N is not a very good index of the available N supply. However, since both the soil and plant nitrate was very low, it must be considered that of the fertilizer nutrients, N was the limiting factor in field No. 7. Potash, evidently, was the limiting factor in field No. 98.

Large amounts of N fertilizer are necessary for maximum production of peas if they are to be grown continuously in the same fields as is the case in South Jersey. In such cases the large amounts of added N help to alleviate the ill effects of root rots. The 60 pounds of N supplied by the mixed fertilizers was inadequate for field No. 7. Some additional N was supplied from organic reserves in the soil. Also, some N may have come from bacterial fixation. However, the N supplied from this latter source is usually small when large amounts of N fertilizer are applied. Yields had removed seventy one pounds of N and considerable N is usually lost by leaching. This resulted in a low N supplied at the end of the growing season. Even so, this lowered supply came at a late period and did not produce any deficiency symptoms nor markedly decrease the crop. The amounts supplied by fertilizer and other sources was evidently satisfactory in field No. 98 where only 45 pounds of N were tied up in the crop.

The P_2O_5 in both plant and soil varied but slightly in the entire season. The constant and relatively high amounts would indicate that this nutrient was ever present in sufficient quantities for the needs of the plant.

The 120 pounds of K_2O supplied by the mixed fertilizer was evidently running very low at harvest time in field No. 98. This is reflected in both the soil and plant analysis for available nutrients. The small amounts of total K_2O taken up in the last 2 weeks of growth (Table 2) is another indication. Field No. 7, evidently starting with a larger reserve of available K_2O was able to supply enough K_2O for a much larger crop. Although the potash contents of both soil and plant dropped during the growing season, the amounts present never approached deficiency levels.

CONCLUSIONS

A study of two fields of canning peas (Thomas Laxton variety) in 1943, yielding 4,300 and 2,400 pounds of shelled peas, respectively, revealed that

1. The high-yielding crop removed 81 pounds of N, 37 pounds of P_2O_5, and 70 pounds of K_2O as compared to 45 pounds of N, 20 pounds of P_2O_5, and 37 pounds of K_2O for the smaller crop.
2. From 55 to 59% of the dry matter was produced and 47 to 58% of the N, 60 to 65% of the P_2O_5, and 24 to 45% of K_2O were absorbed in the last 14 days of growth.
3. The two crops utilized approximately 1.90, 0.85, and 1.55 pounds of N, P_2O_5, and K_2O, respectively, to produce a hundred pounds of shelled peas.
4. The shelled peas contained only about one third of the N, two fifths of the P_2O_5, and one fourth of the K_2O necessary to produce the crop. Returning the vines and pods to the fields would be an important factor in maintenance of the soil fertility.
5. Soil and plant analysis can be used to advantage in studying the nutrient status. Specifically in these studies, soil and plant analysis revealed (a) that N and K_2O levels dropped markedly as the season progressed, while P_2O_5 remained fairly constant; (b) the 60 pounds of N supplied by the mixed fertilizer was exhausted in producing the 4,300 pounds of shelled peas; and (c) the 120 pounds of K_2O supplied by mixed fertilizer was inadequate for the 2,400 pound yield. Reserves of K_2O in this field were evidently too low for this crop yield.

LITERATURE CITED

1. Wolf, B. The rapid determination of total nitrogen, phosphorus, and potassium in plant material. Ind. and Eng. Chem., Anal. Ed., 16:121–123. 1944.
2. ———. Rapid determination of soluble nutrients in soil and plant extracts. Ind. and Eng. Chem., Anal. Ed., 15:248–251. 1943.
3. ———. Determination of nitrate, nitrite and ammonium nitrogen. Ind and Eng. Chem., Anal. Ed., 16:446–447. 1944.

CROP RESIDUE MANAGEMENT IN DRY-LAND CROP PRODUCTION[1]

O. R. Mathews[2]

METHODS of crop production that involve leaving at least a part of the crop residues on the surface have been under trial for many years in cooperative experiments at field stations in the Great Plains and the Columbia River Basin at which the Division of Dry Land Agriculture of the U. S. Dept. of Agriculture has been the operating or cooperating agency. Results at different stations have appeared as parts of general publications from time to time. This paper has been prepared to bring together some typical results and give an over-all perspective to the role of crop residues in dry-land crop production.

The earliest trials were comparisons of the plow and the disk, and were made to determine whether the rather expensive operation of plowing could be omitted for one or more years without reducing yields, rather than for the specific purpose of leaving stubble on the surface. Later, as implements that left more debris on the surface came into wider use and as the need for protection against wind erosion, particularly on land being fallowed, became more apparent, experiments were conducted for the specific purpose of determining the effect on yields of implements leaving surface residues. The extensive use of the combine-harvester, which leaves all the straw on the land, further increased the need for crop residue studies, as it was feared that plowing under the larger quantity of straw and stubble produced in favorable years might leave the soil too loose.

In the results reported here the methods under trial have been divided into three groups, *viz.*, (1) methods that leave all or nearly all of the crop residues on the surface, (2) methods that leave part of the crop residues on the surface, and (3) methods that leave little or no residues on the surface. Other phases of the experiments, such as the time of operations and the use of different types of tillage equipment, have been necessarily omitted. The results presented, however, restrict comparisons to those in which the different initial operation were performed at approximately the same time.

The implements used for leaving as much of the residues on the surface as possible were the plow and the lister without moldboards, the rod weeder, the Noble blade, and different types of sweep implements ranging from comparatively narrow duckfoot shovels to sweeps 30 inches or more in width. The implements leaving part of the residue on the surface were the disk, oneway, and lister. In all cases where the residue was considered completely buried, the plow was the implement used.

---

[1]Contribution from the Division of Dry Land Agriculture, Bureau of Plant Industry, Soils, and Agricultural Engineering, U. S. Dept. of Agriculture. Most of the work was in cooperation with the state experiment station in the respective states. In recent years some of the work was carried on in cooperation with the Soil Conservation Service. Received for publication January 2, 1945.

[2]Senior Agronomist.

In any discussion of crop residues it should be emphasized that not only the original tillage operation but also the follow-up operations to control weeds determine how much remains on the surface. For example, a single operation with a oneway buries part of the residue but leaves some of it on the surface. The use of a rod weeder following the oneway returns to and leaves on the surface a considerable portion of the buried residue. On the other hand, repeated use of the oneway may bury or destroy the portion left on top by the original operation. In experiments cited, there has been an attempt to consider surface conditions throughout the cultural period as well as following the first operation.

EXPERIMENTAL RESULTS

The results are presented separately for fallowed land and for cropped land, because the cultivation of land that is being fallowed extends over much the longer period.

RESULTS ON FALLOWED LAND

The primary purpose of fallowing in dry-land areas is to store moisture. To accomplish this purpose the land is kept free from weeds and other vegetation for an entire growing season. Thus, there is a long period during which crop residues may have an opportunity to affect moisture penetration and conservation. Fall-sown small grains are usually seeded in September or early October, and in the Southern Great Plains they frequently produce enough cover to protect the soil against wind erosion. Fallowed land on which spring grains are to be grown lies bare over winter and is particularly subject to injury by wind erosion unless protected by cultivation or by crop residues, preferably the latter. The early studies on land being fallowed were made to determine whether crop residues would control wind erosion, and if so, whether controlling it by this method would increase or decrease crop yields. Later, as it became evident that yield differences were small, replicated experiments were initiated to obtain a more precise measure of them.

Stubble disintegrates rather rapidly during summer in the Great Plains, and the quantity of residue left on the surface at the end of the fallow season is not large, even when as much of it as possible is retained. Particularly in the northern Plains, where most of the grain was binder harvested, cultivation during the summer buried or destroyed practically all the residue on plots where the straw was partially incorporated into the soil by the initial tillage operation, and little information is available on methods that retain a partial residue cover during the entire fallow season. In Oregon, where the summer is almost rainless, decomposition of straw is slower, summer cultivation to control weeds is not needed so frequently, and it is possible to represent the three types of cover more adequately.

Yields of grain grown on land fallowed by different methods are presented in Table 1.

Results show that the position of the crop residue had little effect on yields, except at Pendleton, Ore. In general, the differences were

TABLE 1.—*Yields of small grains on land fallowed by methods leaving different quantities of crop residues on the surface.*

Station	Years	Crop	Residue on surface, bu.	Part of residue on surface, bu.	Residue buried, bu.
Havre, Mont.	1926–43	Spring wheat	14.0	—	16.3
Havre, Mont.	1942–43*	Spring wheat	31.3	—	29.5
Havre, Mont.	1938–43	Barley	25.1	—	28.6
Judith Basin, Mont.	1932–43	Winter wheat	13.8	—	14.7
Sheridan, Wyo.	1925–42	Spring wheat	20.1	—	20.5
Archer, Wyo.	1938–42	Winter wheat	19.5	20.8	—
Archer, Wyo.	1924–36	Winter wheat	11.3	—	11.7
Dickinson, N. Dak.	1928–43	Spring wheat	20.5	—	19.8
Dickinson, N. Dak.	1924–43†	Spring wheat	18.9	—	17.1
Mandan, N. Dak.	1933–43	Spring wheat	20.3	—	19.9
Belle Fourche, S. Dak.	1932–43	Spring wheat	15.9	—	15.3
North Platte, Nebr.	1937–43‡	Winter wheat	—	24.0	22.4
Akron, Colo.	1928–41	Winter wheat	12.1	11.8	11.8
Akron, Colo.	1942–43*	Winter wheat	34.6	32.4	35.3
Colby, Kans.	1932–43	Winter wheat	13.6	14.2	13.7
Hays, Kans.	1939–43	Winter wheat	12.8	13.0	13.0
Garden City, Kans.	1943	Winter wheat	18.5	—	20.4
Moro, Ore.	1940–43*	Winter wheat	30.6	30.8	31.2
Pendleton, Ore.	1940–43*	Winter wheat	33.7	36.0	38.3
Pendleton, Ore.	1931–40	Winter wheat	—	36.6	41.8

*Replicated randomized experiments. A significant difference between treatments was shown at Pendleton only. The experiments at Moro and Pendleton were conducted by the Soil Conservation Service, with the Bureau of Plant Industry, Soils, and Agricultural Engineering and the Oregon Agricultural Experiment Station as cooperating agencies.
†Plots with residue on surface were slightly favored by location.
‡1941 not included.

small and well within the range of experimental error. Long time results at Havre, Mont., appeared to favor the plow over the duck-foot; but a replicated randomized experiment, results of which are available for only 2 years, failed to show a significant difference between treatments. Similar experiments at Akron, Colo., and Moro, Ore., likewise failed to show significant yield differences. At Pendleton the maintenance of residues on the surface significantly reduced yields. The moisture supply at Pendleton has been sufficient so that the quantity of available nitrates has affected yields, and it appears that reduced nitrate formation is responsible for the lower yields on the plots with residues on the surface.

Unworked or undercut combine stubble collects snow and stores more moisture during the first winter of a fallow period than land without such cover. Fallow cultivation at most northern stations begins in the spring, however, and all the methods under trial generally have the benefit of this initial storage.

RESULTS ON CROPPED LAND

Results of a number of experiments comparing the effect of different methods of cultivation where a crop was grown on small grain stubble land are presented in Table 2. This table restricts comparisons to those where the different types of operations were performed

at the same time and omits many comparisons of fall plowing with shallow spring cultivation. Tillage operations for winter grains generally started soon after harvest and at southern stations covered a period of several months before seeding. With spring-sown small grains there was little margin of time between the initial cultural operation and seeding, and no subsequent opportunity to kill weeds not destroyed in the initial operation. No data are available from Oregon, as the grain production of the dry-land wheat section of that state is conducted almost exclusively on an alternate fallow and crop basis.

TABLE 2.—*Yields of crops on small grain stubble cultivated by methods leaving different quantities of crop residue on the surface.*

Station	Years	Crop	Residue on surface, bu.	Part of residue on surface, bu.	Residue buried, bu.
Havre, Mont.	1917–29	Winter wheat*	—	6.5	6.1
Havre, Mont.	1928–43	Spring rye*	—	7.7	8.5
Huntley, Mont.	1917–43	Winter wheat*	—	8.6	8.6
Sheridan, Wyo.	1918–43	Winter wheat*	—	14.2	15.1
Sheridan, Wyo.	1940–43	Spring wheat	17.3	17.4	17.5
Sheridan, Wyo.	1938–42	Corn	15.8	—	14.5
Archer, Wyo.	1924–41	Spring wheat*	—	6.2	6.5
Archer, Wyo.	1924–42	Winter wheat*	—	7.3	7.5
Archer, Wyo.	1927–43	Corn	11.4	—	10.9
Dickinson, N. Dak.	1924–43	Spring wheat*	—	9.4	11.6
North Platte, Nebr.	1940–43	Winter wheat	15.3	—	13.9
North Platte, Nebr.	1937–43	Winter wheat*	—	13.3	12.5
Akron, Colo.	1925–43	Winter wheat*	—	5.4	5.6
Akron, Colo.	1930–43	Spring wheat	—	4.4	4.5
Akron, Colo.	1930–43	Oats	—	12.6	15.2
Akron, Colo.	1930–43	Barley	—	10.2	12.3
Colby, Kans.	1932–43	Winter wheat*	—	7.5	6.9
Colby, Kans.	1932–43	Winter wheat	—	8.5	8.3
Hays, Kans.	1924–43	Winter wheat*	—	16.8	17.7
Hays, Kans.	1931–43	Winter wheat	12.0	—	11.2
Hays, Kans.	1930–42	Winter wheat†	14.6	13.3	12.3
Hays, Kans.	1943	Winter wheat‡	9.3	11.8	10.6
Garden City, Kans.	1941–42	Winter wheat	17.7	16.0	—
Woodward, Okla.	1933–43	Winter wheat*	—	18.4	18.4
Woodward, Okla.	1941–43	Winter wheat	23.4	25.7	26.1
Lawton, Okla.	1924–43	Winter wheat	—	11.7	14.7
Lawton, Okla.	1924–43	Winter wheat*	—	13.9	14.8

*Rotations where plowing is followed by 1, 2, 3, or 4 years of disking.
†Seedbed studies involving four tillage implements on six dates.
‡Replicated randomized experiment; no significant difference between treatments.

The data in the table to which the first footnote applies afford especially good comparisons because the methods rotate over the same plots, thus reducing experimental error due to location. In connection with these sets of rotations, plots disked each year were used at a number of stations. The yields of such plots are not used in the table, but in most cases plots disked each year seemed to become somewhat less productive than those plowed at intervals.

Yield differences due to difference in placements of residue were small. All spring-sown small grains produced slightly higher yields on land where residues were buried. It is believed that a small difference actually exists, and that it is due chiefly to weed infestation. Shallow cultivation leaves more weed seeds in position to germinate promptly, and the greater production obtained from early seeding makes it undesirable to delay seeding long enough to kill the weed crop emerging after the initial cultivation.

Results with winter wheat were less consistent, but the average yields on land with all or part of the residue on the surface were more often higher than lower than on plowed land. The greatest difference in favor of plowing was at Lawton, Okla., in the first experiment listed, where plowing every year is compared with disking every year. Yields on land alternately plowed and disked (last line, Table 2) were only 0.9 bushel higher on the plowed than on the disked land.

In the two experiments with corn, yields were slightly higher on the plots with residue on the surface. In an experiment at Bellefourche, S. Dak., not shown in the table, conducted during a period of low yields and frequent failures, there was a very slight difference in favor of plowing.

SUMMARY OF YIELDS

In general it can be stated that in the Great Plains and in the drier part of the Columbia River Basin, leaving crop residues on the surface has had so little effect on yield that other factors, such as erosion control, weed control, and ease and economy of operation can be safely used to determine the extent to which the practice should be adopted. Any lack of nitrification due to the surface cover has been of no consequence since there was still a release of nitrates sufficient to supply the crops that could be produced with the quantity of moisture available. In the area represented by Pendleton, Ore., residues decreased yields, and if the practice is to be used there the other advantages must counterbalance the reduction in yield. This reduction may be avoided by the use of nitrogen fertilizers.[3]

EROSION PROTECTION

WATER EROSION

The effect of crop residues on erosion by water has not been measured in these experiments, except for one location in Oregon, but observations have been made over many years. Residues on the surface resist water erosion, but this does not mean that surfaces without residues are always susceptible, or that residues afford complete protection. Newly plowed land, particularly if plowed when dry enough to be lumpy, resists erosion and permits water to enter the soil readily, and the land remains resistant until rains and tillage to control weeds and prepare a seed bed have mellowed and leveled it.

Water erosion is less of a problem in the Great Plains than in regions

[3]Mimeographed circular by Stephens, D. E., Mitchell, G. A., Oveson, M. M., and Belanger, Joseph, entitled "Methods of Disposal of Crop Residues for Growing Wheat After Fallow in Eastern Oregon."

of higher rainfall, although summer rains are often torrential and the possibility of runoff is greater than might be expected from the average annual rainfall. In some years there are no rains heavy enough to cause material runoff from land given reasonably good cultivation. In other years the heavy rains come at times when the soil is able to absorb them. Under some conditions, however, the impact of rain may seal the surface and cause heavy runoff. Residues on the surface break the force of the raindrops and make the soil less apt to seal over and reduce the damage from runoff that does occur by offering a physical obstruction to rapid water movement. Where spring-sown grains are grown on spring-cultivated small grain stubbleland, the presence or absence of residues has little effect on erosion, as the newly worked land is usually in condition to absorb ordinary spring rains, and the crop generally reaches a stage of growth where it offers some resistance to erosion by the season of the year when torrential rains are most likely to occur. Stubbleland that is prepared early for a crop of winter wheat, as in the southern Great Plains, is usually in good condition to absorb rains during the early part of the cultural period, but the land may be worked down enough before seeding time so that surfaces without residues may wash if heavy rains occur.

The greatest danger of erosion is on land being fallowed, as it becomes compacted, and the quantity of water in the soil makes the penetration of additional water difficult, but an erosion hazard is present on any land that is worked down level and not protected by crops or residues.

In the Columbia River Basin severe erosion is most likely to take place during the latter part of the winter after land has been fallowed, and occurs chiefly when water from melting snow runs over the land. Soil and water losses at the location where they were measured were lowest on land with all the residue on the surface, with little difference shown between bare land and land where the residue was partially incorporated into the soil.

WIND EROSION

Observations on wind erosion cover many years, but experimental evidence is lacking. We know of no field experiments where differences in wind erosion resulting from different placements of crop residues have been measured. The nature of the problem makes it impossible to obtain reliable results on small plots, because on small areas soil is less likely to start moving than on larger ones, and also because soil movement originating on susceptible areas can quickly affect less susceptible ones.

Protection against wind erosion is needed chiefly in the late winter and early spring. At that time the soil is frequently so mellow that it will move unless protected by a crop, crop residue, or emergency cultivation.

Tillage to leave residues was given impetus in the portions of the central and northern Great Plains where fallowing was desirable because it increased yields, but undesirable because bare fallow or planted fallow on which the crop did not make enough fall growth to

protect the surface was likely to blow during the winter or spring. This blowing frequently took place on land without snow cover at times when the soil below the immediate surface was frozen and emergency cultivation could not be given. Experiments with plowless fallow, under way since 1924, have demonstrated that at most locations crop residues have been efficient in protecting surfaces that would otherwise be bare or nearly bare during the winter period. At Belle Fourche, S. Dak., however, the surface of the heavy clay soil became so mellow during a year of shallow surface cultivation that binder stubble did not afford adequate protection. Land fallowed for winter wheat in the southern Great Plains does not need winter protection as frequently as fallow left bare over winter, as wheat on fallowed land generally makes enough growth to form a resistant plant cover before winter sets in. Residues are more often needed on cropped land planted to winter wheat, as the wheat on such land may fail to make enough fall growth to cover the ground.

An undisturbed small grain stubble renders a soil safe from wind erosion over winter. Stubbles of row crops do not prevent all soil blowing, but tall stubbles of such crops as sorghums and corn reduce the amount of blowing and make it less destructive. In some sandy portions of the Great Plains where grain sorghums are the principal crop, continued agriculture may depend on the proper use of residues. After land has been cultivated in the spring, all but the sandy soils are usually safe for the summer regardless of whether a crop residue is left on the surface.

WATER STORAGE

Measurements of infiltration rates have not been made in connection with the stubble mulch experiments, but moisture determinations at the beginning and end of storage periods have been made at some stations to determine the net result of leaving residues on the surface. At Hays, Kans., in the experiment for the period 1930–42 (Table 2), the average quantity of water saved between harvest and seeding over a 10-year period was highest on the chiseled plots and lowest on the plowed plots, but the average difference between these two extremes was only about ⅓ inch of water. In the replicated experiment, results from the different replications were contradictory, but the average gain in moisture during the period between harvest and seeding was slightly higher on the plots cultivated with the chisel and with the 30-inch sweeps than on the plowed and the onewayed plots.

At North Platte, Nebr., five years' results show that water accumulation in land being fallowed was slightly higher on disked or listed land than on plowed land, but the average difference was less than ⅓ inch. This represents the difference in accumulation over periods of approximately 15 months, extending from July in one year to October the following year. Three years' data are available for a comparison of cultivation with sub-surface sweeps with plowing, listing, and disking. In this test results from year to year were inconsistent, but the average showed the highest storage on subtilled land and the

lowest on plowed land, the average difference between the two being about ½ inch.

At Archer, Wyo., five years' results showed that differences in water storage due to placements of residues were even smaller than at Hays and North Platte. In the test at Havre, Mont., extending over a period of 17 years, water storage for the fallow period from May to September was slightly higher on plots plowed in May than on the plot duckfooted in May. In experiments in Oregon (Table 1) storage of moisture for the fallow year was higher on the plots with surface cover than on the plowed plots, but average figures on accumulation are not at hand. The difference was much greater in the surface foot than at lower levels, indicating that the straw on top reduced the loss from the soil by evaporation during the rainless summer period.

SOIL STRUCTURE

Soil structure in the cultivated layer of soils is influenced by the condition of the soil when it is tilled and by the tillage implement used. Comparison of soil structure between land with and without residues on the surface is complicated by the fact that different tillage implements are used. Probably the only statement that can be safely made is that the granules of soil on the immediate surface are protected from the direct impact of rain by residues, and the surface is less likely to become crusted. No permanent effect in creating increased granulation has been noted. On the contrary, there has been some indication that the continued retention of crop residues in a thin surface layer increases the organic matter content of this layer and slightly reduces its tendency to flocculate. It seems apparent that any differences in soil structure thus far brought about by difference in placements of crop residues may be completely obscured by a single major tillage operation such as listing, deep one-waying, or plowing.

WEED CONTROL

More weeds usually emerge on land cultivated with implements that leave the crop residues on the surface than on land where the tillage operation has buried more of the weed seeds. Spring grains on disked, duckfooted, or subsurface-tilled small grain stubble land planted to grain soon after the tillage operation are almost invariably weedier than on plowed land. This does not decrease the yields in all years, as in favorable seasons the crop may outgrow the weeds, and in adverse years there may still be enough weeds on the plowed land to offer severe competition to the crop.

Implements used for subsurface tillage generally cut off all the weeds, and if the tillage operation is followed by several days of dry weather, are effective in killing them. If cultivation is followed by rain, small weeds are likely to resume growth. In wet years land with residues on the surface requires more tillage operations than land cultivated with implements that bury more of the weeds, but none of the operations is as expensive as plowing and the cost of a season's operations is usually lower. Some subsurface sweeps are now being

built with projecting fingers back of the blade to disturb the undercut layer of soil more and make the sweeps more efficient in killing weeds. Duley and Russell[4] recommend pulling an implement that they have named the "treader" behind subsurface sweeps to break up lumps, kill weeds, firm the soil, and anchor the residue by pressing part of it into the surface soil. The rod weeder is an efficient implement for killing weeds and at the same time maintaining crop residues on the surface.

OTHER FACTORS

Surface residues might be expected to have some influence on insect damage and on plant diseases, but up to the present time no appreciable injury from these sources has been observed in these experiments, although instances of injury within the dry-land area have been reported. In areas where residues on the surface do not decrease yields, there is a question as to how much effort can be profitably expended in keeping all of the residue from heavy crops on the surface. Implements such as the oneway and lister, if followed by a rod weeder, leave a considerable but not unmanageable quantity of crop residues on the surface. Undercutting blades and the various kinds of wide sweeps can go through a heavy stubble when the soil is firm unless excessive weed growth has occurred, but may experience difficulty in subsequent operations if the soil is loose and moist and the stubble tough or tangled. Under such conditions it is difficult to operate the implement shallow enough to kill weeds without an undue amount of clogging. Leaving more residue on the surface than is required for erosion control may be an uneconomic practice. Residues left on the surface may blow away and may require some sort of a packing operation to incorporate enough of them into the soil for safe anchorage. Such packing may also be required to prepare a suitable seedbed, as the undercut layer of soil is left very loose. Implements for the continued management of residues left on the surface are not yet perfected, but constant efforts to improve them are being made.

Differences in yields resulting from differences in soil and organic matter loses through erosion have not been apparent in these experiments, but methods that do not control erosion may be expected to show reductions in yield eventually.

CONCLUSIONS

The results of experimental work at locations throughout the Great Plains and at two locations in the Columbia River Basin show that, except for the one location where lack of available nitrogen was a controlling factor, moisture storage and yields of crops were about the same under three conditions of tillage and disposition of organic residues, namely, leaving all the residues on the surface,

[4]Mimeographed publication entitled "Use of Treaders with Subsurface Tillers." Issued by the Nebraska Agricultural Experiment Station in cooperation with the Soil Conservation Service in April, 1944.

leaving a portion of the residues on the surface, and completely burying the residues by plowing.

Cultural practices that leave part of the crop residues on the surface are in general use over much of the area because they are adapted to low-cost, extensive-type farming. Maintaining additional quantities of residues on the surface for greater erosion control is desirable if the protection afforded compensates for certain accompanying disadvantages, such as mechanical difficulties and the greater effort necessary to control grassy weeds. Present indications are that the amount of effort that should be expended in keeping residues on the surface will be determined by the need for erosion control with especial regard to the long-time effects of erosion and the relative cost of tillage rather than by the expectation of materially influencing current yields.

FIELD BINDWEED, *CONVOLVULUS ARVENSIS* L., ROOT FRAGMENTS MAY GROW[1]

L. V. Sherwood[2]

PEOPLE interested in weed control have long cautioned against cultural practices which permit the transportation of root fragments, particularly of perennial weeds, from one field to another or from different areas of the same field. One of the specific recommendations made to farmers for control of perennial weeds stresses the importance of root fragments.

During the period 1936–41, experiments were conducted at Urbana, Ill., to determine if new field bindweed infestations could be initiated by root fragments (Fig. 1).

METHODS

Large roots of field bindweed were taken from the soil, cut into specific sizes, and immediately transplanted at given depths in a previously prepared soil. In some cases the transplantings were watered to assure sufficient moisture; in others, normal rainfall was depended upon. For each root fragment, data were kept indicating whether it came from the first, second, third, or other foot layer of soil; the length of the fragment; the depth of planting; and the growth response of the fragment. An effort was made to encourage as many fragments as possible to grow.

DISCUSSION OF RESULTS

Variable results were obtained during the years 1936–39 (Table 1). However, there was growth from some of the root fragments each year. The relationship between root diameter and growth was marked. The larger the diameter of the fragment, the more likely it was to grow. A similar relationship existed between length and growth. Fragments 3 inches or more in length usually grew well, while short fragments were weak or failed to grow.

Fragments obtained from soil below the plow depth were much more likely to grow than those taken from shallower depths. Even when samples were taken from areas where field bindweed had grown unmolested and the upper plant sections were of typical root structure rather than renewed "stem" growth, the root fragments from second- and third-foot soil layers grew better than those from the first foot of soil. However, the differences were not nearly as marked as on fragments taken from areas previously molested by tillage. All fragments which were taken close to the surface in a fallowed area failed to grow.

Root fragment plantings were made in 1940 (Table 2) in such a manner as to help answer some of the questions raised but not entirely answered by previous tests (Table 1). Tests in 1940 indicated that watering had an unfavorable effect upon the growth of root fragments. The rainfall for 1940 was extremely low during the growing season, and the adverse effects of watering were unexpected.

[1]Contribution from the Department of Agronomy, Illinois Agricultural Experiment Station, Urbana, Ill. Published with the approval of the Director. Received for publication January 9, 1945.

[2]Assistant Professor of Crop Production, on leave of absence for war service.

TABLE 1.—*Growth of field bindweed root fragments at Urbana, Ill., 1936–39, as summarized from various detailed data.*

Planting date	Depth in soil from where taken	Depth of planting inches	Number	Length, inches	Moisture	Condition of plants from which fragments were taken	Results
				1936			
July 13–17	1–5 ft.	2–12	280	0.5–6.0	Watered	From an area where corn grew the previous year	Only 4% of the entire planting grew Fragments 3 inches or longer grew best Fragments from 2nd and 3rd foot soil layers grew best Fragments planted 2 inches deep grew best
				1937			
June 4....	1–3 ft.	2–12	120	1.0–6.0	Watered	From an area where corn grew the previous year	25% of the second planting grew None from the other plantings grew Fragments 5 and 6 inches long grew best Fragments from 2nd and 3rd foot layers grew best Fragments planted less than 6 inches deep grew best
July 8.....	1–3 ft.	2–12	120	1.0–6.0	Watered		
Aug. 21....	1–3 ft.	2–12	120	1.0–6.0	Watered		

				1938			
July 14....	1–3 ft.	3	48	6	Watered	Unmolested Tops removed	For all three plantings an average of 90% of the fragments from unmolested plants grew, and 59% from plants which were molested by previous cultivations
Aug. 4.....	1–3 ft.	3	48	6	Watered	Unmolested Tops removed	
Sept. 13...	1–3 ft.	3	48	6	Watered	Unmolested Tops removed	Most of those not growing were from the upper foot layer of soil
				1939			
June 15....	1–3 ft.	3	24	6	Watered	Unmolested	87.5% grew, with the fragments from the 2nd and 3rd foot producing the most vigorous growth
June 23....	4 in.	3	40	4	Watered	From fallowed area	None grew
June 23....	4 in.	3	40	4	Not watered		
Aug. 24....	1–2 ft.	3	24	6	Watered	Unmolested	37.5% of the total grew, with those from 2nd foot layer producing the most vigorous growth

TABLE 2.—*Growth of field bindweed root fragments at Urbana, Ill., 1940.**

Factor tested	Date of planting	Kind of tissue	No. of frag-ments	Length of frag-ments, inches	Moisture†	Condition of plants from which fragments were taken	Growth of frag-ments, %
Watering at time of planting	Sept. 5	Root	25	6	Watered	Unmolested	36
	Sept. 6	Root	25	6	Watered	Unmolested	64
					Watered fragments		50
	Sept. 5	Root	25	6	Not watered	Unmolested	36
	Sept. 6	Root	25	6	Not watered	Unmolested	100
					Av. for unwatered fragments		68
Root reserves	Sept. 6	Root	25	6	Watered	Unmolested	64
	Sept. 6	Root	25	6	Watered	Tops kept removed	0
Size of fragments	Sept. 5	Root	25	6	Watered	Unmolested	36
	Sept. 5	Root	25	3	Watered	Unmolested	4
Root vs. stem growth	Sept. 6	Root	25	6	Watered	Unmolested	64
	Sept. 6	Stem	25	6	Watered	Unmolested	0

*All fragments taken from plow depth and planted about 3 inches deep.
†0.48 inch of rain fell on September 9, 1940.

Root reserves may have had considerable effect upon the growth of root fragments as indicated by the poor growth of those taken from roots which were starved. Starving was accomplished by preventing all top growth during the growing season previous to obtaining root fragments. Small fragments also made poor growth as compared to large pieces, the latter apparently having a greater food reserve.

FIG. 1.—One year's growth from a single root fragment of field bindweed. Planted July 8, 1937, and dug June 23, 1938.

Fragments obtained from the plow layer of soil were considered anatomically as stem rather than root development. This may account for the relatively poor growth of fragments from the first foot of soil in the 1936–39 experiments (Table 1). In 1940, samples were carefully taken in the surface 7 inches of soil. These samples were labeled "stems" in contrast to "roots" which were obtained in lower soil layers. None of these "stems" grew; however, 64% of the "roots" produced growth. In previous years some of the fragments from the first foot of soil grew, but this may have been because part of the fragments were typically "roots" rather than "stems". Also, some of

TABLE 3.—*Root fragment study at soil bins, 1941.*

No. of fragments	Length of fragments, inches	Kind of tissue	Source of fragments	% moisture in soil		Inches of rainfall after planting		Av. weight of fragments, grams	% of fragments producing the following kinds of growth*				
				Where fragments were taken	Where fragments were planted	Within 4 days	Within 10 days		Dead	Small	Medium	Large	Total growth
				First Planting, June 7									
50	6	Root	Unmolested area	16	17	2.80	3.69	0.54	20	6	30	44	80
50	6	Stem	Unmolested area	16	17	2.80	3.69	0.65	44	20	18	18	56
50	3	Root	Unmolested area	16	17	2.80	3.69	0.22	34	38	26	2	66
50	6	Root	Cultivated field†	19	17	2.80	3.69	0.58	98	2	0	0	2
				Second Planting, July 9									
25	6	Root	Unmolested area	20	16	0.02	0.24	0.66	100	0	0	0	0
25	6	Stem	Unmolested area	20	16	0.02	0.24	0.47	100	0	0	0	0
25	6	Root	Cultivated field	18	16	0.02	0.24	0.87	100	0	0	0	0
25	6	Stem	Cultivated field†	18	16	0.02	0.24	0.62	100	0	0	0	0
				Third Planting, Aug. 15									
25	6	Root	Unmolested area	21	18	0.92	1.81	0.50	28	8	24	40	72
25	6	Stem	Unmolested area	21	18	0.92	1.81	0.39	32	36	20	12	68
25	6	Root	Cultivated field	22	18	0.92	1.81	0.89	4	4	24	68	96
25	6	Stem	Cultivated field	22	18	0.92	1.81	0.57	24	16	28	32	76

*Growth reading taken August 15 on first planting and October 20 on second planting.
†Corn field.

the samples for previous years were taken from unmolested areas where typical root growth develops in all soil layers. It can be concluded from these experiments that samples obtained from the first foot of soil from unmolested areas are more likely to grow than are those from areas previously cultivated.

A further test made in 1941 (Table 3) indicated that the amount of moisture in the soil where the transplantings were made may have determined whether any root fragments would grow. In a second planting of fragments made in soil with a low moisture content and with little rainfall during the period immediately following transplanting, the fragments failed to grow.

Fragments obtained from a corn field during the early part of the summer produced little or no growth; whereas, those taken from the same area on August 15 grew rapidly. The latter were collected after sufficient time had elapsed since cultivation to permit some food storage; whereas, those gathered earlier were presumably low in food reserves.

CONCLUSIONS

1. Even though transplanted field bindweed root fragments do not always grow; enough do grow so that they are a factor in the spread of the weed and must be taken into account in any control program.

2. Root fragments are much less likely to grow if (a) tillage operations are performed when the soil is dry enough to pulverize easily and break loose from the fragments; (b) the soil is pulverized so as to leave the root fragments free from large soil particles; or (c) rainfall is light immediately after cultivations.

3. Root fragments from field bindweed which has been recently disturbed by plowing or other deep cultivations are less likely to grow than those from undisturbed areas.

4. Shallow cultivations are less likely to spread field bindweed by root fragments, since fragments less than 3 inches long grow poorly if at all. Furthermore, fragments from close to the surface are less likely to grow than those from deeper depths.

5. Surface type cultivators may be superior to other types in preventing the spread of field bindweed by root fragments.

REGISTRATION OF IMPROVED WHEAT VARIETIES, XVII[1]

J. ALLEN CLARK[2]

SIXTEEN previous reports present the registration of 70 improved varieties of wheat. In 1943 four varieties were registered.[3] Four varieties have also been approved for registration in 1944. These are:

Class and Varietal Name	Reg. No.
Soft Red Winter	
Sanford	336
Hard Red Winter	
Wichita	337
Hard Red Spring	
Mida	338
White	
Orfed	339

SANFORD (REG. No. 336)

Sanford (C. I. 12026[4]) was developed by the Agronomy Department of the Georgia Agricultural Experiment Station and the Division of Cereal Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture, from a P1068 × Purplestraw^3 backcross. P1068 is a strain very closely related to Kanred. Both were developed at the Kansas Agricultural Experiment Station. The original and backcrosses were made at Experiment, Ga., by R. P. Bledsoe. The second backcross was made in 1928 and last selected in 1934. In the fall of 1939 two selections, H-264-1-2-3-3-3 and H-264-1-2-3-3-5, were bulked and the seed increased under the name Sanford. Seed was first distributed for commercial growing in 1940. Sanford is similar to Purplestraw, except that it has longer apical awnlets, plumper grain, matures a few days later, is moderately resistant to leaf rust, and has higher yields. The purpose of the work was to transfer the leaf-rust resistance of P1068 or Kanred to Purplestraw. It was estimated that 45% of the wheat grown in Georgia in 1943–44 was Sanford and some is grown in Alabama and South Carolina.

Sanford has been tested in advanced nursery tests of from 6 to 10 replications during the 10-year period, 1935–44. These yields can be compared with Gasta, a selection of Purplestraw wheat also developed at the Georgia station. The yields, which furnish the basis for regis-

[1]Registered under a cooperative agreement between the Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture, and the American Society of Agronomy. Received for publication February 5, 1945.

[2]Senior Agronomist, Division of Cereal Crops and Diseases, U. S. Dept. of Agriculture. Member of the 1944 committee on Varietal Standardization and Registration of the Society charged with the registration of wheat varieties.

[3]CLARK, J. ALLEN. Registration of improved wheat varieties, XVI. Jour. Amer. Soc. Agron., 36:447–452. 1944.

[4]C. I. refers to accession number of the Division of Cereal Crops and Diseases.

tration, are shown in Table 1. For further information on Sanford wheat see the 52d Annual Report of the Georgia Agricultural Experiment Station.

TABLE 1.—*Annual and average yields in bushels per acre of Sanford and Gasta wheats grown at Experiment, Ga., for the 10 years, 1935–44.*

Year	Sanford	Gasta	Gain or loss	Percentage of Gasta
1935	25.0	15.8	9.2	158.2
1936	28.4	24.3	4.1	116.9
1937	29.8	14.1	15.7	211.3
1938	12.2	9.0	3.2	135.6
1939	41.0	32.1	8.9	127.7
1940	31.4	26.6	4.8	118.0
1941	24.6	26.0	−1.4	94.6
1942	37.3	30.5	6.8	122.3
1943	24.2	19.3	4.9	125.4
1944	27.1	24.1	3.0	112.4
Average 10 years	28.1	22.2	5.9	126.6

WICHITA (REG. No. 337)

Wichita (Ks. 2739, C. I. 11952) was developed by the Agronomy Department of the Kansas Agricultural Experiment Station and the Division of Cereal Crops and Diseases of the U. S. Dept. of Agriculture, from an Early Blackhull × Tenmarq cross. The cross was made at Manhattan, Kans., in 1929 and was last selected in 1935. The Texas, Oklahoma, Nebraska, and Colorado Agricultural Experiment Stations cooperated in testing this variety in comparison with others in the hard red winter wheat region. Seed was increased in Kansas, Oklahoma, and Texas, and first distributed for commercial growing in the fall of 1944.

The superior characteristics of Wichita are early maturity, high yield and test weight, and more satisfactory gluten quality than the Early Blackhull variety which it should replace. In reaction to leaf and stem rust Wichita is similar to Early Blackhull, being generally susceptible, although early maturity often enables these varieties to escape part of the damage. Wichita matures about 6 days earlier than Tenmarq and Blackhull but is 1 day later than Early Blackhull. Lodging at maturity has been slightly less than Early Blackhull but greater than Tenmarq. Tests indicate that Wichita is more winter hardy than Early Blackhull and nearly as hardy as Tenmarq. The heads are large, bearded, and have long beaks. The chaff usually has black stripes. The grain is not so hard as some of the hard red winter varieties but probably will be graded as hard red winter.

Yields and test weights are available from nursery and plot experiments at Manhattan for 6- and 7-year periods and from 11 other stations in the state for from 1 to 3 years. In cooperative experiments with farmers, it has been included in 59 tests, including the 1943 crop.

It has also been included in experiments at the Lawton, Okla., and Chillicothe and Denton, Tex., stations for 3 or 4 years. Data

from all these tests were submitted by L. P. Reitz, who applied for registration. Some of the yields are recorded in Table 2.

TABLE 2.—*Average yields in bushels per acre of Wichita and four standard varieties of wheat.*

Stations	Years	Wichita	Tenmarq	Early Blackhull	Blackhull	Turkey
Manhattan plots....	1938–43	26.5	24.6	20.5	21.0	19.1
Manhattan nursery	1937–43	33.9	29.0	29.8	25.2	24.5
Hays..............	1941–43	23.7	23.6	23.9	19.1	16.9
Colby..............	1941–43	46.8	44.5	39.9	40.6	39.2
Tribune	1941–43	32.9	33.1	28.2	—	25.6
Garden City........	1941–43	24.1	24.3	21.0	21.1	16.9
Meade.............	1941–43	19.0	16.3	12.5	11.0	10.3
Dodge City...	1941–43	27.5	24.3	21.9	20.6	20.0
Kingman...........	1942–43	14.5	13.4	12.9	13.7	14.6
Hutchinson.........	1941–43	24.9	21.1	18.9	16.5	17.1
Wichita............	1941–43	28.6	25.2	24.2	19.3	21.6
Belleville...........	1943	13.6	14.2	14.4	21.6	18.0
Smith Center.......	1943	24.2	22.1	23.7	—	23.0
Average, 41 station years............		27.9	25.6	23.6	(37)	21.0
Percentage of Early-Blackhull........		118.2	108.5	100.0	92.6	90.0

MIDA (REG. No. 338)

Mida (Ns. 2829, C. I. 12008) was developed by the Agronomy Department of the North Dakota Agricultural Experiment Station cooperating with the Division of Cereal Crops and Diseases of the U. S. Dept. of Agriculture from a Ceres-Double Cross (R. L. 625) × Mercury cross. The cross was made at Fargo, N. Dak., in December 1933. Two generations a year were grown by the further use of the greenhouse and the strain resulting in Mida (F_5) was last selected in 1936. The superior characters of Mida are high yield and resistance to stem and leaf rust and to bunt. It is tall with often blackish awns, strong straw, and large kernels with heavy test weight. The quality of Mida is of medium strength and declared satisfactory for all-purpose bakers flour. The wheat was increased first at Fargo and later under contract with seed growers in the state and in 1944 over 15,000 bushels were distributed to some 800 North Dakota farmers.

Mida was included in the Uniform Regional Nursery for the 3 years 1939–41 and in plot experiments at five North Dakota experiment stations for the 4 years 1940–43. It was also included in field plot experiments in neighboring states and was made a uniform variety for the region in 1944. Average yields for some of these experiments are shown in Tables 3 and 4.

ORFED (REG. No. 339)

Orfed (Wn. 3300, C. I. 11913) was developed by the Agronomy Department of the Washington State Agricultural Experiment

TABLE 3.—*Average yields in bushels per acre of Mida and three other varieties of wheat grown in the Uniform Regional Nursery in four states during the 3 years 1941–43.**

Variety	North Dakota (11)†	Minnesota (10)	South Dakota (3)	Montana (9)	Average (33)	Percentage of Thatcher
Mida	32.9	32.1	25.9	30.4	31.4	113.8
Thatcher	29.9	23.2	23.6	31.1	27.6	100.0
Regent	28.6	24.2	24.3	26.5	26.3	95.3
Marquis	19.9	16.7	15.3	28.4	20.8	75.4

*For further information see Waldron, L. R., *et al.*, Mida wheat. N. Dak. Agr. Expt. Sta. Circ. 68. 1944.
†Figures in parenthesis indicate station years.

TABLE 4.—*Average yields in bushels per acre of Mida and four other varieties of wheat grown in plot experiments at five North Dakota experiment stations during the 4 years 1940–43.*

Variety	1940 (5)*	1941 (5)	1942 (5)	1943 (5)	Average (20)	Percentage of Thatcher
Mida	14.0	26.7	38.5	28.6	26.9	112.6
Pilot	12.7	26.4	37.7	28.4	26.3	110.0
Rival	12.5	26.8	36.4	26.7	25.6	107.1
Thatcher	13.9	22.5	31.9	27.3	23.9	100.0
Renown	11.9	23.3	31.3	26.1	23.2	97.1

*Figures in parenthesis indicate station years.

Station and the Division of Cereal Crops and Diseases of the U. S. Dept. of Agriculture from an Oro × Federation cross. The cross was made by V. H. Florell at the University of Idaho in 1931. An F_2 population was given O. A. Vogel who selected the present line in 1937. It was entered in the uniform yield and bunt nurseries of the western region in 1940. It is an awned wheat with white chaff and white kernels. It is intermediate for winter and spring habit and can be successfully grown in southeastern Washington and adjacent Idaho and Oregon from both fall and spring seedings. Its superior character-

TABLE 5.—*Yield in bushels per acre and test weight in pounds per bushel for Orfed and Hymar wheats grown in plots or nursery experiments at Pullman, Pomeroy, and Walla Walla, Wash., 1940–44.*

Variety	1940	1941	1942	1943	1944	Average	Percentage of Hymar
			Yield				
Orfed	50.3	58.1	59.3	62.0	53.2	56.6	115.5
Hymar	46.3	41.2	51.9	58.6	47.1	49.0	100.0
			Test Weight				
Orfed	62.7	62.2	61.2	63.9	63.0	62.6	103.0
Hymar	60.0	61.4	60.3	61.6	60.5	60.8	100.0

istics are good yields, high test weight, and resistance to shattering, lodging, and bunt. It also has good milling and baking properties. It has performed sufficiently well in varietal tests at Pullman, Pomeroy, and Walla Walla, Wash., to warrant its recommendation for the areas of Washington that commonly grow fall-sown, soft white, and club varieties.[5] It also can be grown as a spring-sown variety to a limited extent, particularly in early seeding, to patch up fall-sown fields of Orfed which have been partly winterkilled. Its superiority in yield and test weight over Hymar, a commonly grown variety in eastern Washington, is shown in Table 5.

Seed of Orfed[6] was first distributed for commercial growing in the fall of 1943.

---

[5]SCHAFER, E. G., VOGEL, O. A., and SWENSON, S. P. Winter wheat for the 1944 crop. Wash. Agr. Exp. Sta. Pop. Bul. 173. 1943.

VOGEL, O. A., and BARBEE, O. E. Comparative performance of wheat varieties in eastern Washington. Wash. Agr. Exp. Sta. Gen. Bul. 450. 1944.

[6]VOGEL, O. A., SWENSON, S P., and HOLTON, C. S. Orfed wheat. Wash. Agr. Exp. Sta. Gen. Bul. 451. 1944.

NOTES

CYANOGAS INJURY TO TOMATO PLANTS INFLUENCED BY POTASH FERTILIZATION

ON MANY occasions cyanogas (calcium cyanide) has been used in the greenhouses in the control of certain insect pests. With a variety of plants of different sizes and ages and degrees of hardness, it has always been a problem to know just how much cyanogas to use without producing injury to some plants and yet control the pest.

During January 1945, one of the greenhouses was fumigated with 5 grams of cyanogas per 1,000 cubic feet of space on each of two consecutive nights. In the greenhouse was a series of potash studies in which a number of tomato plants (Rutgers) varied from those severely deficient in potash to those abundantly supplied. Each plant that was medium to severely deficient in potash was severely burned, but plants in a healthy state showed no signs of injury.

FIG. 1.—Plant on left is deficient in potash and severely injured with cyanogas; the one on the right is normal and uninjured.

The illustration in Fig. 1 shows the type of injury. This has happened on two separate occasions during the winter. The type of injury has also been strikingly characteristic.—JACKSON B. HESTER, *Agricultural Research Department, Campbell Soup Co., Riverton, N. J*

AGROPYRON JAPONICUM, AN UNTENABLE NAME

IN 1886, seed of a grass from New Zealand was introduced into California by the Agricultural Experiment Station of the University of California at Berkeley. The grass made a good record and was distributed for cultivation in 1889 to increase winter grazing.

Seed was also sent to U. S. Government Experiment Stations in the southern states where again its record was good and mention of the grass began to appear in the literature. This would not be any cause for comment now if the grass had been properly listed under its then recognized name *Brachypodium japonicum* Miq. Through some error in labels the name *Agropyron japonicum* had become attached to this "Japanese rye" or "Japanese wheat-grass". Its first published mention is by Tracy (4)[1] in 1891 and although Hitchcock (1) lists this as "name only" the following description did appear: "In its general habit this is much like fescue-grass[2] (*Bromus schraderi*), but does not grow as large and the heads are somewhat bearded. It will grow later in the season, however, and is a perennial." Three years later Tracy (5) again discusses the grass and its forage possibilities, once more mentioning its perennial habit and resemblance to rescue grass.

Final use of the name was by Wickson (7) when he gave the history of its introduction and the information that "the first California-grown specimen was sent to the late Dr. Vasey, who named it as a new species." This specimen seems to have been lost for it is not in the U. S. National Herbarium according to Hitchcock (1). There was preserved, however, in the Agronomy Division Grass Herbarium, Division of Agronomy, University of California, Davis, a sheet of some later planting which is good *Brachypodium japonicum* (Miq., 1867). This name, in conformity with the International Rules of Botanical Nomenclature, must give way to *Brachypodium miserum* (Thunb.) Koid. based on *Festuca misera* Thunb. (1784).

That the East Asian introduction was actually a *Brachypodium* was recognized by Tracy himself (6) and soon after by Lamson-Scribner (3). However, the descriptions, though brief, and particularly the plate by Wickson, are ample to take the name *Agropyron japonicum* Tracy out of the class of either *nomina nuda* or *nomina dubia* and place it as a legitimate synonym under *Brachypodium miserum*.

The matter could end here were it not that there has been published subsequently an *Agropyron japonicum* Honda which, together with a variety *hackeliana* Honda, are treated by Honda (2) in his thorough survey of Japanese grasses. In light of the earlier homonym, i.e., *A. japonicum* Tracy, the nomenclature of *A. japonicum* Honda must be revised as follows:

Agropyron hackelianum (Honda) comb. nov.

A. angustifolium Hackel ex Nakai, Report Veg. Isl. Quelp. 21, 1:14; Mori, Enum. Pl. Cor. 35. 1922; not *A. angustifolium* Schultes. *A. japonicum* Honda var. *hackelianum* Honda, Tokyo Bot. Mag. 41: 385. 1927; Jour. Fac. Sci. Sec. III. Bot. 28. 1930.

Agropyron hackelianum var. **japonicum** (Honda) comb. nov.

A. japonicum Honda, Tokyo Bot. Mag. 41: 384. 1927; Jour. Fac. Sci. Sec. III. Bot. 28. 1930.

The species belongs in Section Braconnotia Godron and has leaves

[1]Figures in parenthesis refer to "Literature Cited", p. 321.
[2]*Sic*, an error for rescue-grass.

4–6 mm wide, the awn of the lemma 3–10 mm long as distinguished from the variety which has leaves 10–12 mm wide and the awn of the lemma 15–18 mm long.

LITERATURE CITED

1. HITCHCOCK, A. S. Manual of Grasses of United States. 1935. (Page 774.)
2. HONDA, M. Monographia Poacearum Japonicarum, Bambusoideis Exclusis. Jour. Fac. Sci. Imp. Univ. Tokyo, Sect. III, Bot. 28. 1930.
3. LAMSON-SCRIBNER, F. Economic Grasses. U. S. D. A. Div. Agrostology Bul. 14. (rev.): 22. 1900.
4. TRACY, S. M. Cooperative Branch Stations in the South. U. S. D. A. Div. of Botany Ann. Rpt. 6. 1891.
5. ————. Forage plants for the South. U. S. D. A. Farmers' Bul. 18:13–14. 1894.
6. ————. A report upon the forage plants and forage resources of the Gulf States. U. S. D. A. Div. Agrostology Bul. 15:29. 1898.
7. WICKSON, E. J. Reports on grasses and forage plants. Univ. Calif. Agr. Exp. Sta. Rpt., 1895–97; 275. pl. 14. f. 1. 1898.

—ALAN A. BEETLE, *Division of Agronomy, University of California, Davis, Calif.*

AGRONOMIC AFFAIRS

THE 1945 MEETINGS

ARRANGEMENTS have been made with the Netherland Plaza Hotel in Cincinnati, Ohio, to hold the annual meetings of the American Society of Agronomy and Soil Science Society of America November 20 to 22, 1945. The National Joint Committees on Fertilizer Application and Nitrogen Utilization will meet on Monday, November 19.

These plans can only be tentative, since at present all meetings are subject to approval by the Office of Defense Transportation. However, we sincerely hope that war and transportation conditions are sufficiently favorable by November so that agronomists can again meet and gain added inspiration for continuing the important job of providing adequate food for our own people and others who may be dependant upon us.

In the meantime, let us continue our good work as individual agronomists and as members of the American Society of Agronomy and the Soil Science Society of America to the end that we may have an early victory and a lasting peace.—G. G. POHLMAN, *Secretary.*

NEWS ITEMS

PROFESSOR F. V. BURCALOW of the University of Wisconsin is now serving in Italy as agronomist with the Foreign Economic Administration, with headquarters in Rome.

—A—

THE ANNUAL MEETING of the Canadian Seed Growers' Association will be held this year at the Ontario Agricultural College, Guelph, June 19 to 21. The officers of the Association are A. M. Stewart, Ailsa Craig, Ont., President; H. P. Wright, Airdrie, Alta., Vice President; and W. T. G. Wiener, Ottawa, Ont., Secretary-Treasurer.

ACCORDING TO *Commercial Fertilizer*, Dr. Ralph W. Cummings, head of the Department of Agronomy of North Carolina State College, has been appointed Director of the North Carolina Experiment Station, but will continue as head of the Department of Agronomy.

—A—

THE JULY, 1944, number of *Agricultural History* carries a concise presentation of the development of range research in the western United States, entitled "The History of Western Range Research", which should be of interest to many agronomists. The article was prepared under the supervision of W. R. Chapline, Chief, Division of Range Research, Forest Service, U. S. Dept. of Agriculture.

—A—

THE *New York Times* carried a recent Stockholm dispatch describing what was termed the world's first loaf of "tetraploid" rye bread which was tasted at a recent meeting of the Swedish Academy of Agriculture. The development of a tetraploid rye with 64 chromosomes and a grain 50% larger than that from diploid rye is credited to Professor Arne Mintzing in experiments at the Svalöv Station.

—A—

ACCORDING TO *Science*, the American Cyanamid Company has made a grant-in-aid for three years to the Arizona Agricultural Experiment Station for investigations into the use of new nitrogen-containing compounds as agricultural fertilizers. A search will be made for compounds that will supply the nitrogen, develop it slowly in the soil, and that will contain nitrogenous material of such solubility that it will not leach rapidly to areas below the root zone.

—A—

DOCTOR LEWIS R. JONES, Professor Emeritus of Plant Pathology at the University of Wisconsin, died in Orlando, Fla., on March 31st at 81 years of age.

—A—

DOCTOR FRANKLIN S. HARRIS, President of Brigham Young University at Provo, Utah, for the past 24 years, will become President of the Utah State Agricultural College at Logan on July 1. Doctor Harris will succeed Doctor E. G. Peterson who retires after 28 years of service. Previous to his appointment to Brigham Young University, Doctor Harris served the Utah State Agricultural College successively as Professor of Agronomy, Director of the School of Engineering and Mechanical Arts, and Director of the Agricultural Experiment Station.

—A—

DOCTOR W. L. BURLISON, University of Illinois, completed 25 years as Head of the Department of Agronomy, Illinois College of Agriculture, on March 31, 1945. His associates recognized the occasion by presenting him with an inscribed gold wrist watch and a parchment commemorating the anniversary. Doctor Burlison has long been prominent in the affairs of the Society, having been Vice President from 1924 to 1926 and President in 1927.

JOURNAL

OF THE

American Society of Agronomy

VOL. 37 | MAY, 1945 | NO. 5

RESPONSES OF COTTON TO SULFUR FERTILIZATION[1]

HENRY C. HARRIS, ROGER W. BLEDSOE, AND P. W. CALHOUN[2]

IT IS well known that sulfur is necessary for the growth of plants, but, as Alway[3] states, it is a slighted element in agricultural research. The purpose of this paper is to present some preliminary results dealing with the effect of sulfur fertilization on the growth of cotton in two widely separated localities of Florida. Even though the results are preliminary, it seems desirable to present them, especially since it is usually assumed that sufficient sulfur is supplied as sulfates in fertilizers or through precipitation to prevent that element from being a limiting factor in crop production.

EXPERIMENT I

This paper deals with three experiments conducted in 1944, two at Gainesville and one at Madison, Fla. The first experiment was conducted on the Experiment Station Farm at Gainesville. The soil type is Arredonda loamy fine sand, and it is in a productive condition. Liberal fertilizer treatments have been applied in the past.

This experiment was exploratory and was designed to give some indication as to whether sulfur, magnesium, or placement of fertilizer would have any effect on the growth of the cotton.

A 4–8–4 fertilizer was used at the equivalent rate of 500 pounds per acre. It was formulated from 60% muriate of potash, uramon, ammonium nitrate, and 48% triple superphosphate, and presumably contained very little sulfates. One third of the nitrogen came from uramon. In the cases where the sulfur was added this was done by substituting 48% potassium sulfate for the muriate of potash in the above mixture. This sulfate mixture supplied a calculated 7.4 pounds of sulfur, or 18.5 pounds of SO_3 per acre.

---

[1]Contribution from the Department of Agronomy, Agricultural Experiment Station, University of Florida, Gainesville, Fla. Published with the approval of the Director. Funds for the Madison experiment were largely furnished by the Sea Island Cotton Bureau of the Florida State Department of Agriculture. Received for publication December 22, 1944.

[2]Associate Agronomist and Associate Agronomist, Florida Agricultural Experiment Station, and Entomologist, Sea Island Cotton Bureau, Florida State Department of Agriculture, respectively.

[3]ALWAY, FREDERICK J. A nutrient element slighted in agricultural research. Jour. Amer. Soc. Agron., 32:913–921. 1940.

The following minor elements in the form of C.P. chemicals were mixed with the fertilizer: Boric acid, 1 pound per acre; copper chloride, 2 pounds; manganese chloride, 3 pounds; and zinc chloride, 2 pounds. Where magnesium was applied the rate was 15 pounds per acre of magnesium chloride.

The fertilizer treatments were as follows: (1) Placed directly under the cotton, no sulfur or magnesium; (2) placed in bands about 8 inches apart, one on each side below the seed level, no sulfur or magnesium; (3) same as 2, but sulfur as K_2SO_4 in the mixture; (4) same as 2, but both sulfur and magnesium in the mixture; and (5) same as 4, but 100 pounds in same band arrangement and 400 pounds plowed under by placing in bottom of furrows.

The treatments were replicated in three randomized blocks. The plots, 12×35 feet, contained three rows of cotton.

The fertilizers were applied April 10, 1944, and the soil was immediately listed. Two days later upland cotton, variety Stoneville 2B, was planted. All plots were sidedressed on May 12 with 50 pounds per acre of ammonium nitrate.

Within 2 weeks after the cotton came up the plants on the plots where sulfur was not applied were retarded in growth and developed a yellow color similar to that of nitrogen deficiency. The plants on all other plots were normal in size and color. Fig. 1 shows this contrast.

FIG. 1.—Upland cotton in experiment 1, May 24, 1944, 42 days after planting. *Left*, with sulfur; *right*, without sulfur.

RELATION BETWEEN NUMBER OF PARENTAL LINES AND THEORETICAL PERFORMANCE OF SYNTHETIC VARIETIES OF CORN[1]

Murray L. Kinman and G. F. Sprague[2]

THE utilization of hybrid vigor has provided the basis for the more recent improvement in corn. Synthetic varieties of corn have been used only to a very limited extent either commercially or as reservoirs of desirable gene combinations. Synthetic varieties are being used to a limited extent among horticultural crops and among the various forage grasses and legumes. One of the new alfalfa varieties, Ranger, is a composite of five strains resistant to bacterial wilt. Under conditions where the annual production of first generation hybrid seed may be impractical synthetic varieties offer an opportunity to utilize an appreciable amount of hybrid vigor.

The purpose of this study was twofold; first, to investigate the type of gene action involved in the inheritance of various quantitative characters having their visible effects in desirable agronomic performance and second, to investigate the manner in which selected inbred parents may be used to best advantage in the production of synthetic varieties of corn.

Few data are available on the actual performance of synthetic varieties. Hayes (1)[3] reported yields of five synthetic varieties which represented combinations of from 8 to 15 lines. The parental lines involved in each synthetic variety were derived from an individual open-pollinated variety. The percentage increase or decrease in yield for the synthetic as compared with the parental variety ranged from -11.7 to $+16.6$

Sprague and Jenkins (8) reported data on the acre yields of the F_1, F_2, F_3, and F_4 generations of four 16-line and one 24-line synthetics and of several open-pollinated varieties. In general, the average yield of the advanced generations closely approximated the average yield of the open-pollinated varieties with which they were compared. The inbred lines involved in these hybrids were chosen for specific characteristics other than combining ability, hence the yields of these synthetics may not be representative of the yields to be expected with adequate selection for combining ability.

Yields of the F_1 and F_2 generations of 8- and 16-line synthetics were reported by Kiesselbach (5). Concerning synthetic varieties in general, he states, "The Nebraska Experiment Station has had a number as productive as ordinary varieties but no better."

[1]Contribution from Farm Crops Subsection, Iowa Agricultural Experiment Station, Ames, Iowa, and the Division of Cereal Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture, cooperating. Journal paper J-1254, Project 163. Received for publication January 19, 1945.

[2]Formerly Research Assistant, Agronomy Section, Farm Crops Subsection, Iowa Agricultural Experiment Station, and Senior Agronomist, Division of Cereal Crops and Diseases and Collaborator Agronomy Section, Farm Crops Subsection, Iowa Agricultural Experiment Station, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 350.

The synthetic varieties compared in the reports cited above were comprised largely of untested parental lines. Hayes, Rinke, and Tsiang (2) present data on the first synthetic made up of lines of proved combining ability. This synthetic was shown to be superior to the standard commercial variety and at least equal to Minhybrid 403 in yielding ability.

Tysdal, Kiesselbach, and Westover (9) reported yields of six synthetic varieties of alfalfa involving from 2 to 18 parental lines. Their yields ranged from 97 to 104% of the mean yield of six standard varieties with which they were compared.

MATERIALS AND METHODS

Seed of the 45 possible single crosses among 10 inbred lines was produced at Ames, Iowa, in 1942. Seed of the F_2 generation of these single crosses was produced in the greenhouse at Beltsville, Md., in the winter of 1942–43. Yield tests of the inbred lines and of the F_1 and F_2 generations of the crosses among them were grown at Ames in 1943. The F_1 generation of the single crosses (1943 Midseason Uniform Test), together with four double crosses, were compared in a 7×7 lattice square experiment with four replications. The 45 F_2's together with the 4 dummy F_2 entries were compared in an experiment of similar design. The 10 inbred lines were compared in an experiment having a randomized complete block design with four replications. The entire test area was divided into four equal parts and one replication from each experiment was assigned to each area at random. This should insure comparable data from each of the three experiments. Each individual replication was bordered with material of similar vigor. Data were recorded on yield, root lodging, unbroken stalks, moisture content of shelled grain at harvest, and percentage damaged kernels.

Formulae are available for computing the performance of the F_2 generation expected on the assumption of either additive or geometric gene action. Other types of gene action are possible, but the statistical procedures for evaluating such action are inadequate at present. The formula used for computing F_2 performance expected on the assumption of additive gene action is that proposed by Wright (10), namely, $F_2 = F_1 - \frac{(F_1 - P)}{n}$. The corresponding formula for computing F_2 performance expected on the assumption of geometric gene action is similar to that proposed by Powers (7),

$$F_2 = \text{antilog of } \frac{2 \log F_{1(P_1 \times P_2)} + \ldots \; 2 \log F_{1(P_{(n-1)} \times P_n)} + \log P_1 \ldots + \log P_n}{n^2}.$$

In both formulae, F_2 represents the expected performance of the F_2 generation of the cross or synthetic variety, F_1 the average performance of all possible single crosses among the parental lines involved, P the performance of the parental lines, and n the number of parental lines involved. The use of either formula implies that all matings are random. Similarly, with each assumption regarding gene action four factors operate in determining the performance of a synthetic variety (8). These are (a) the number of lines involved, (b) their mean performance as lines, (c) the mean performance of all possible single crosses among them, and (d) the amount of self pollination. In these studies this latter factor has been ignored as corn is almost completely cross pollinated. This factor may be of great importance in crops where some degree of natural self fertilization occurs, and Tysdal, Kiesselbach, and Westover (9) have discussed the theoretical possibilities of various levels of cross pollination in alfalfa synthetics.

EXPERIMENTAL RESULTS

The parental line, F_1, and the observed and expected F_2 acre yields are presented in Table 1. The F_1 yields occupy the lower left-hand

triangle, F_2 yields the upper right-hand triangle, and yields of the parent lines the diagonal of the table. Within each group of three F_2 yield values in the upper triangle, the upper figures represent the observed acre yield and the middle and lower figures represent those expected on the assumption of arithmetic and geometric gene action, respectively. Analyses of variance were calculated for these sets of values for all characters studied.

In preliminary calculations comparisons were made by twos, i.e. observed vs. arithmetic, observed vs. geometric. The error terms for the different comparisons were very similar so a combined analysis for the three variables was calculated and a summary of these analyses is presented. The analysis break down for acre yield is presented in

TABLE 1.—*A comparison of parental line, F_1, and observed and calculated yields for the F_2 populations of 45 single crosses grown at Ames, Iowa, in 1943.**

	Hy	R46	B2	WF9	38–11	K159	Oh 07	Oh 04	WV7	CI.14
Hy	31.9	49.8 58.7 53.9	49.7 55.4 51.6	52.3 48.6 45.0	64.7 56.3 49.3	62.6 60.5 56.5	56.7 51.9 47.2	47.2 53.0 42.5	47.0 49.6 43.0	39.0 40.0 24.1
R46	81.6	39.8	58.1 60.8 56.9	56.7 61.2 54.5	61.1 64.0 55.5	58.9 66.3 62.5	56.3 51.4 48.1	50.5 48.6 41.3	44.9 47.9 43.2	31.4 52.7 29.6
B2	75.3	82.2	39.0	47.8 67.9 58.3	59.3 65.3 56.1	68.3 66.1 62.2	55.1 69.5 59.2	47.8 56.0 45.4	45.1 59.9 50.3	37.9 40.8 25.0
WF9	67.1	88.2	102.1	28.5	58.9 57.2 48.9	61.6 58.7 54.3	54.8 57.1 49.4	57.5 52.9 41.7	49.1 48.0 41.4	40.5 43.0 24.9
38–11	83.4	94.9	97.9	87.0	26.5	66.9 66.4 58.6	56.9 59.7 50.3	38.0 41.8 35.4	54.7 61.6 48.1	36.1 40.2 23.6
K159	80.1	87.9	87.8	78.2	94.6	49.8	61.5 62.3 56.7	54.2 67.1 52.8	47.7 58.0 50.6	48.6 53.2 30.5
Oh 07	73.7	68.6	105.2	85.7	92.0	85.4	28.5	58.6 50.6 40.6	47.2 55.6 45.6	46.6 47.0 26.3
Oh 04	82.6	69.7	84.9	84.1	62.8	101.8	79.5	15.1	35.0 33.3 29.2	39.4 38.0 20.7
WV7	73.2	65.9	90.2	71.8	100.0	81.0	86.9	49.0	20.1	25.8 27.3 17.9
CI. 14	62.7	84.1	60.8	70.4	65.8	80.1	78.5	67.2	43.3	2.7
Av. F_1	75.5	80.3	87.4	81.6	86.5	86.3	83.9	75.7	73.5	68.1

*Difference necessary for significance at the 5% level, F_1 = 12.1 bu.; F_2 = 7.8 bu.; P = 6.3 bu.

Table 2. The sum of squares for "method" may be partitioned orthogonally into observed vs. arithmetic and observed + arithmetic vs. geometric. This latter component has no important significance. By a different orthogonal partition the observed vs. geometric component may be separated.

TABLE 2.—*Analysis of variance of observed and calculated F_2 acre yields in bushels.*

Source of variation	D/F	Sum of squares	Mean square	F value
Crosses	44	13105.07	297.84	
Method	2	2053.28	1026.64	51.38**
Observed vs. arithmetic	1	229.12	229.12	11.47**
Observed+arithemtic vs. geometric	1	1824.16	1824.16	
Cross × method	88	1756.38	19.98	
Total	134	16916.73		

**Exceeds 1% point.

The F values for the observed vs. calculated comparisons for the five variables studied are presented in Table 3. The F_2 performance expected on the assumption of arithmetic gene action is in closer agreement with observed values than that expected on the basis of geometric gene action for acre yield, root lodging, and damaged kernels. Both sets of calculated values are in good agreement with observed values for unbroken stalks and per cent of moisture in grain. The comparisons among arithmetic vs. geometric values have little significance as these two sets of values are not independent, both being calculated from the same series of F_1 and parental means.

TABLE 3.—*Coefficients of variation for the five variables and F values for the comparisons of interests.*

Variable	Coefficient of variation	F values		
		Observed vs. arithmetic	Observed vs. geometric	Arithmetic vs. geometric
Yield	9	11.47**	43.32**	99.36**
Root lodging	14	10.70**	29.24**	4.57*
Unbroken stalks	1	1.48	0.61	0.26
Damaged kernels	41	0.14	12.73**	10.21**
Moisture	5	0.10	0.11	0.36

*Exceeds 5% point.
**Exceeds 1% point.

It may be well to emphasize that the differences between the actual values and those calculated for arithmetic gene action are deviations from the simple additive scheme. These non-additive deviations may be caused by dominance or epistatic effects. The calculation of an "arithmetic value" does not imply that all of the genes involved in the expression of the particular character operate in an additive fashion. It does provide a measure of the average effect of all gene substitutions affecting a particular character and assumes that this average effect of gene substitution is similar over

all genotypes encountered in the population. One may conclude from the data presented in Table 3 that the assumption of arithmetic gene action is a somewhat closer approximation to the facts than is the assumption of geometric gene action. However, as will be shown later, either type of gene action leads to essentially the same conclusions regarding the most efficient number of lines to produce a synthetic.

THE MOST EFFICIENT NUMBER OF INBRED LINES TO BE INCLUDED IN A SYNTHETIC VARIETY

Yield data for the 10 inbred lines and the possible single crosses were used to calculate theoretical yields of synthetic varieties involving from 2 to 10 inbred lines. For use in these calculations the lines were arranged in order of descending mean-combination ability as based on single cross yields. The mean-combining ability in bushels per acre for these 10 lines was as follows: B2, 87.4; 38–11, 86.5; K159, 86.3; Oh 07, 83.9; WF9, 81.6; R46, 80.3; Oh 04, 75.7; Hy, 75.5; WV7, 73.5; and CI.14, 68.1.

Two sets of yields were calculated, one assuming arithmetic gene action and the other geometric gene action. The calculated yield of the synthetic involving the two highest combining inbreds, B2 and 38–11, was based on the actual yield of the single cross and the parental inbreds. The calculated yield of the three-line synthetic involved the mean of all possible single crosses among the three highest combining inbreds, B2, 38–11, and K159, and the yield of the parental inbreds. The other calculated yields were obtained in a similar manner. The results are presented in Table 4. These data indicate with the material used in this study that five or six lines were most efficient under the assumption of arithmetic gene action and six lines most efficient when geometric gene action was assumed.

TABLE 4.—*Calculated acre yields of the F_2 generation of synthetic varieties, assuming additive and geometric gene action with different numbers of component lines.*

Number of lines involved	Yield in bushels per acre		
	F_1 mean	F_2 mean arithmetic	F_2 mean geometric
2	97.9	65.3	56.1
3	93.4	76.1	68.7
4	93.8	79.3	73.1
5	91.6	80.2	74.7
6	89.2	80.2	75.8
7	86.7	79.0	74.2
8	84.4	77.9	73.9
9	82.8	77.0	73.1
10	79.9	74.7	69.6

It has been a common assumption when speculating on the number of lines to be included in a synthetic, that the F_1 mean yield would be a constant value, exceeding that of the open-pollinated variety by a

certain percentage. Thus, for each increase in the number of lines in the synthetic, the difference between the calculated F_2 and the F_1 value is diminished. Therefore, the more parental lines involved, the higher would be the yield of the resulting synthetic.

This assumption of a constant mean yield for all F_1 combinations seems unwarranted. If any series of inbred lines is arranged in order of mean combining ability, the mean yield of all possible single crosses will be greater for the best two, three, or four lines than when a larger number of lines are involved. This is well illustrated by the data in Table 4.

The consequences arising from these two concepts are presented graphically in Fig. 1. The assumed F_1 means were chosen partially for convenience but are in general agreement with data from single cross yield tests where comparisons could be made with open-pollinated varieties. The mean yield of the inbred parents was assumed to be 40% of the open-pollinated variety for both sets of calculations. Under either concept the yield of advanced generation synthetic approaches the yield of the F_1 mean as an asymptote. The implications as to the most efficient number of lines to be used, however, differs greatly under the two conditions. In general, the most efficient number of lines to be included in a synthetic variety will vary with the range in combining ability among the inbreds available as parents.

SYNTHETICS FROM COMBINATIONS OF TOP CROSSES

Mangelsdorf (6) has suggested that synthetic varieties produced by combining tested top crosses may be of value. It is possible to compare the theoretical performance of such synthetics with synthetics involving the same lines but combined as lines or single crosses. Yield data were available from the 1930 tests which involved all of the 55 possible single crosses among 11 inbred lines, top crosses involving these same 11 lines, and the top-cross parent variety, Four County White. No data were available on the yield of the inbred parents and a mean yield of 12 bushels per acre was assumed. The formula used for calculating yields of synthetics involving combinations of top crosses was $\frac{2n^2TC + n^2v + (n^2 - n)\ F_1 + np}{4n^2}$, where TC equals the mean yield of the top crosses involved and v equals the yield of the variety used as top-cross parent. The results of these calculations are presented in Table 5.

The yield of the top-cross parent variety was 24.3 bushels per acre. The yields of individual single crosses ranged from 21.3 to 60.6 and the top crosses from 21.7 to 44.8 bushels per acre. On the basis of the calculated yields it appears possible to produce synthetics which will yield materially more than the parent variety. In this set of comparisons synthetics made up of lines or single crosses were consistently superior to those produced by combining top crosses with the exception of the 2-line synthetic. It should be emphasized, however, that the majority of the 11 lines involved in these tests had been isolated from the parent variety. The difference between "single-cross" and "top-cross" synthetics would diminish as the single and

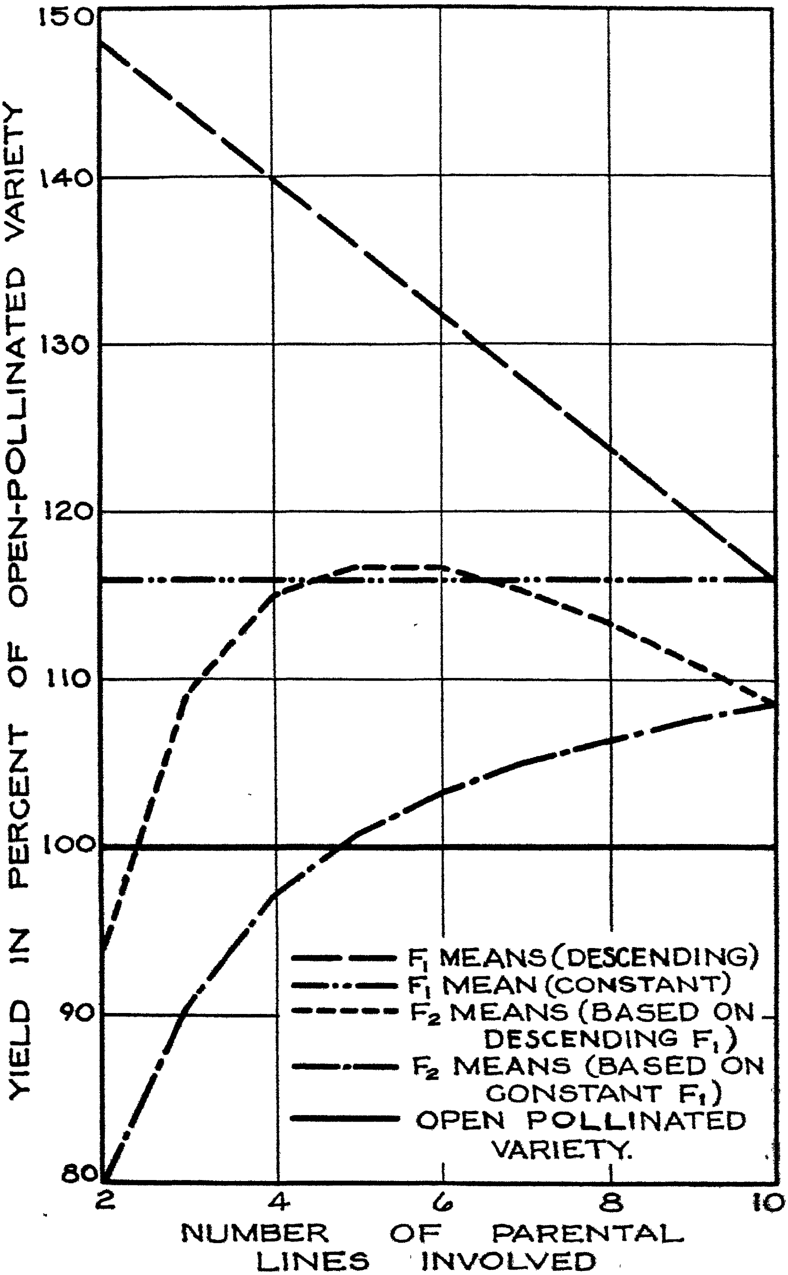

FIG. 1.—Contrast of two assumptions regarding F_1 means and their effect on the most efficient number of parent lines to be combined in a synthetic.

TABLE 5.—*Theoretical yields of synthetic varieties based on combinations of single crosses and of top crosses.*

Number of lines involved	Acre yield in bushels			
	F_1 mean	Top cross mean	F_2 mean calculated from combinations of single crosses	F_2 mean calculated from combinations of top crosses
2	60.6	43.6	36.3	40.7
3	57.9	43.0	42.6	41.4
4	53.6	41.5	43.2	40.1
5	50.8	40.9	43.0	39.3
6	49.0	39.9	42.9	38.4
7	47.4	39.1	42.3	37.7
8	45.6	37.8	41.4	36.6
9	44.0	37.1	40.4	35.8
10	42.4	37.0	39.4	35.4
11	40.5	35.6	37.9	34.2

top crosses approached equality in yield and a reversal might be obtained if the mean of the top-cross yields were the greater.

SYNTHETICS FROM COMBINING LINES INBRED FOR ONLY ONE GENERATION

It is possible to increase the yield level of a synthetic involving a given number of lines in two ways, namely, by (a) increasing the F_1 mean yield, and (b) increasing the inbred mean yield. The latter appears the easier to accomplish. Jenkins (3) has presented data suggesting that inbred lines acquire their individuality as parents of top crosses very early in the inbreeding process and remain relatively stable thereafter. First year selfed lines may yield 75% or more of the open-pollinated variety. Potentially high combining S_1 lines may be identified if they are top-crossed at the time of the first selfing. Synthetic varieties resulting from a combination of such S_1's should possess a higher yield level than those resulting from combinations of more highly inbred and less vigorous lines of the same combining ability. Such a procedure for establishing synthetics with recurrent selection to maintain or possibly improve their yielding ability has been proposed by Jenkins (4).

A comparison of the effect of inbred yield level on the yield level of the synthetic is presented in Fig. 2. Equal yields of the resulting single crosses have been assumed for each of the inbred yield levels chosen. No data are available to test the validity of this assumption that the crosses among vigorous lines with little inbreeding will equal those among lines inbred for a longer period. The three yield levels of the inbred lines were 25, 40, and 75% of the open-pollinated variety. The 25 and 40% levels would include most of the inbred lines now being used commercially and the 75% level was chosen to represent superior S_1 lines. The calculated yields of synthetics from the 75% level are not only greater than for those involving lines of lower yield but, in addition, a smaller number of lines is required for greatest efficiency.

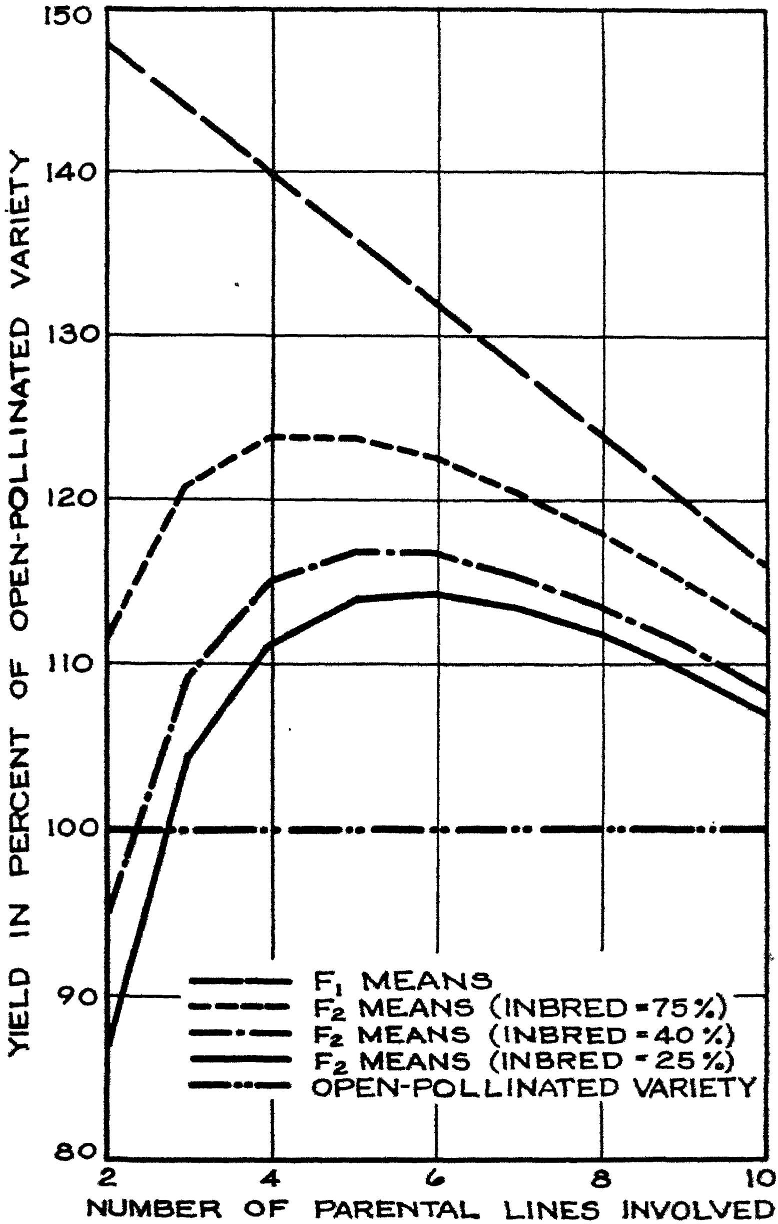

FIG. 2.—Effect of inbred mean yield on the yield of synthetic varieties.

DISCUSSION

In corn, synthetic varieties appear to have their greatest usefulness where (a) maintenance of inbreds is hazardous, (b) the farming public

is not educated to the value of double crosses, and (c) as convenient reservoirs of desirable gene combinations. The calculations presented here are applicable to only the first two of these conditions. Synthetic varieties of corn have not been used commercially to any appreciable extent. One reason for this may have been that the synthetics so far produced and tested have involved from 8 to 24 lines. Results presented here indicate that four to six lines is the optimum number for highest yield.

The actual production of a synthetic offers little difficulties. In corn it can be produced most easily by bulk planting of equal quantities of seed of the inbred lines, or of all possible single crosses among these lines, under conditions of isolation. When conditions permit, the second procedure would be most satisfactory. The same procedures appear to be equally feasible with cross-pollinated horticultural or forage crops. It is probable in this field that synthetics will have their greatest usefulness. The use of tested S_1 lines appears to offer the greatest promise as components of a synthetic under conditions where early testing is feasible.

SUMMARY

A comparison of observed F_2 data and calculated F_2 values assuming arithmetic or geometric gene action indicates somewhat closer agreement between the observed values and those computed on the assumption of arithmetic gene action. Slight departures from either scheme of gene action do not invalidate the conclusions regarding the most efficient number of lines constituting a synthetic variety.

In general,. the most efficient number of lines to be included in a synthetic will vary with the range in combining ability among the inbreds available as parents. On the basis of this study, four to six lines appeared to be the most efficient number.

Synthetic varieties involving the same parental lines may be expected to have a slightly higher yield level when combined directly than when combined as top crosses.

No data are available which permit a comparison of single cross yields between vigorous lines with little inbreeding and the progeny of these lines when more highly inbred. If it should be established that the combining ability of such lines is essentially equal, then synthetic varieties produced by combining first generation selfed lines should be superior to those produced by combining more highly inbred but less vigorous lines.

LITERATURE CITED

1. HAYES, H. K. Present day problems in corn breeding. Jour. Amer. Soc. Agron., 18:344–363. 1926.
2. ————, RINKE, E. H., and TSIANG, Y. S. The development of a synthetic variety of corn from inbred lines. Jour. Amer. Soc. Agron., 36:998–1000. 1944.
3. JENKINS, MERLE T. The effect of inbreeding and of selection within inbred lines of maize upon the hybrids made after successive generations of selfing. Iowa State College Jour. Sci., 9:215–236. 1935.
4. ————. The segregation of genes affecting yield of grain in maize. Jour. Amer. Soc. Agron., 32:55–63. 1940.

5. KIESSELBACH, T. A. The possibilities of modern corn breeding. Proc. World Grain Exhibition and Conf., Canada, 2:92–112. 1933.
6. MANGELSDORF, P. C. Use of multiple top crosses in southern corn improvement. Mimeo. Rpt. First Southern Corn Improvement Conf., 1:33–35. 1939.
7. POWERS, LEROY. Inheritance of quantitative characters in crosses of two species of Lycopersicon. Jour. Agr. Res., 63:149–174. 1941.
8. SPRAGUE, G. F., and JENKINS, MERLE T. A comparison of synthetic varieties, multiple crosses and double crosses in corn. Jour. Amer. Soc. Agron., 35: 137–147. 1943.
9. TYSDAL, H. N., KIESSELBACH, T. A., and WESTOVER, H. L. Alfalfa breeding. Nebr. Agr. Exp. Sta. Res. Bul. 124. 1942.
10. WRIGHT, SEWELL. The effects of inbreeding and crossbreeding on guinea pigs. U.S.D.A. Bul. 1121. 1922.

GROWTH AND DEVELOPMENT OF KENAF, *HIBISCUS CANNABINUS* L., WITH SPECIAL REFERENCE TO FIBER CONTENT OF THE STEMS[1]

JULIAN C. CRANE AND JULIÁN B. ACUNA[2]

WITH the introduction of the kenaf plant, *Hibiscus cannabinus* L., into Cuba as a source of soft fiber for the manufacture of sugar bags and other related articles, the determination of the proper time for harvesting in order to obtain the greatest amount of highest quality fiber per unit of land was one of the problems encountered. Although the investigation reported here is of a preliminary nature, it offers a partial solution to the problem.

REVIEW OF THE LITERATURE

Dekker (2)[3] and Horst (5), working in Java with kenaf, reported that higher yields of fiber were obtained if the plants were allowed to attain maturity than if they were cut and retted at some earlier stage. Horst, in his study to determine the percentage of fiber in plants harvested at different growth stages and also the percentage of fiber in "thick" as compared with "thin" stems, found that plants harvested too green (97 days after planting), which "still had all their leaves and were very full of sap", yielded 1.66 to 2% of fiber. Plants harvested at seed maturity, however, yielded 6.44%. He noted that the yield of high-quality fiber was between these two figures, probably at 4 or 4.5%.

Horst found that the percentage of fiber from air-dried "thick" stalks of a particular variety was 18.5, whereas the percentage of air-dried "slender" stalks was 33.9. He also reported that in another green variety the weight of the bark (which consisted of from 30 to 50% of fiber) constituted about a third of the weight of the stalk. Thus the fiber content of the dried stalks varied from 10 to 17%. By cutting the stalks into thirds in one experiment and into quarters in another, he found that although the lower part of the stem had the greatest amount of fiber, the middle part had the highest percentage of fiber. He advanced the suggestion that the amount of fiber increases in proportion to the square of the relative increase of the stem; therefore, by increasing the height of the plants, a considerable increase in the yield of fiber will result.

Van Gorkom (4) and Zegers Ryser (9) reported that, on the average, green stems contain 1.5 to 2% fiber, whereas El Kilany (3) states that the ratio of fiber yield to green-crop weight is from 7 to 10%. Michotte (6) reports that in Central Asia this plant yielded between 11 and 22% fiber of the dry weight of its stems.

---

[1]Joint contribution from the Office of Foreign Agricultural Relations, U. S. Dept. of Agriculture and the Cuban Agricultural Experiment Station, Havana, Cuba. This study was made possible by funds provided through the United States Inter-Departmental Committee on Cultural and Scientific Cooperation and funds from the Government of Cuba. Received for publication January 25, 1945.

[2]Associate Agronomist, Office of Foreign Agricultural Relations, U. S. Dept. of Agriculture, and Head, Department of Botany, Cuban Agricultural Experiment Station, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 358.

Popova (7), working in Russia, stated that the best time for harvesting the kenaf plant was just previous to the time of flowering, during the most intense period of which, he noted, there was a marked decrease in the longitudinal growth rate of the stem. He found that *Hibiscus cannabinus* practically attained its maximum height just previous to flowering and that the rate of growth diminished when flowering began. As there was some difference of opinion as to the actual percentage of fiber in the stem and the proper time for harvesting kenaf, the following study was made under Cuban conditions in an effort to trace the development of fiber in the stem and associate this development with the various phases of plant growth throughout the life of the plant.

EXPERIMENTAL METHODS

This investigation was conducted on a Matanzas clay soil of rather poor fertility. The land was plowed and cross-plowed to a depth of 8 or 10 inches and then harrowed. Seed was planted on August 24 (it was later determined that planting at this time was from 3 to 4 months late for fiber planting), but it did not germinate until August 30 after a rain the previous day had made soil conditions favorable. Sixteen rows were planted 20 inches apart and the same number of rows were planted 8 inches apart. Seeds were sown rather thickly in the row but after the plants had reached a height of 8 to 10 inches they were thinned to a distance of approximately 1½ inches between plants. Shortly after germination, the plants in the 8-inch-row plot were yellow and showed signs of being starved for lack of nitrogen. This plot was totally abandoned and the plants later were found to be infested severely with nematodes. Approximately 1 month after germination and each week thereafter until seed maturity, two 5-foot sections of plants from the 20-inch rows were selected at random and carefully dug. These plants were taken to the laboratory where the green weight of stems, leaves, and roots was obtained as well as measurements and moisture percentage of the stems. The stems were tied in bundles and dried in an oven for 2 or 3 days before being placed in a retting tank. It was found that if the plants were not dried considerably before submerging them in water, a much longer time for retting was required. Retting generally took from 10 to 15 days, after which the fiber was stripped from the stems, washed thoroughly, and dried in an oven before weighing. The pith, or central woody cylinders, were also washed thoroughly and dried along with the fiber.

RESULTS

The rate of growth and the amount of rainfall throughout the experimental period are presented graphically in Fig. 1. As is typical of all other plants when the rate of growth of kenaf is plotted against time, a sigmoid curve is obtained. The growth rate during the formative stages was slow but speeded up during the elongative period and finally decreased again during maturation. Kenaf is a rapid-growing plant in that the average stem elongation during some periods was over 1 inch a day. These findings rather closely agree with those of Popova (7) in that the period of most rapid elongation occurred just previous to the time of intensive flowering and after this stage was reached the growth rate rapidly decreased. Rainfall appeared to be adequate, but the dry period during the latter part of October and the first part of November probably hastened maturity.

From the data presented in Table 1 the ratio of roots, stems, and leaves to one another is seen to have remained about the same throughout the season or until the leaves dropped the first part of

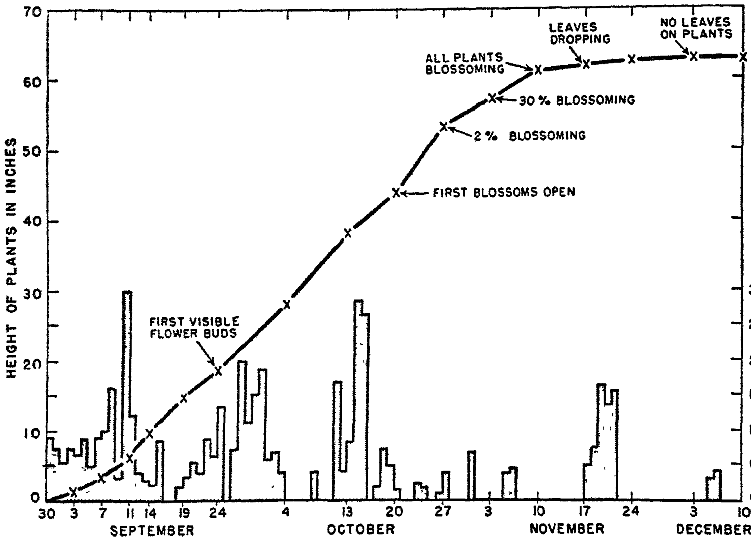

FIG. 1.—Growth and development of kenaf planted on August 24.

December. There was a gradual increase in the percentage of fiber in the stems from 1.9% when the first samples were harvested to 5.5% when practically all of the plants were in blossom. After this stage was reached there was no further increase in fiber content.

These data are in close agreement with data presented by Horst (5), but so far as percentage of fiber is concerned there is no advantage to be gained by delaying harvest beyond the period when all plants have started to blossom. With a progressive increase in fiber content from the date of the first sampling to the time when all plants were in flower, there was an accompanying decrease in moisture content from 87.9 to 72.9%. With the exception of 76.5% moisture in the stems of the samples harvested during a rain on November 17, the moisture remained at approximately 73% from the time the plants started to blossom until maturity.

Fig. 2 shows, on a dry weight basis, the relative percentages of fiber, pith or central woody cylinder, and cortical tissue other than bast fiber (obtained by difference) throughout the development of the plant. There was an increase of 7% in the amount of fiber during the period from October 4 to November 3, while the amount of pith for the same period increased 15%. Both of these increases were made at the expense of a corresponding decrease in the percentage of nonfibrous, cortical tissues. Changes in the relative composition of the stem apparently reached their maximum about November 3 and small variations in data following this sampling date are attributed to error in sampling and experimental technic. Data presented in Fig. 2 on the percentage of fiber in relation to the dry weight of the stem compare favorably with data reported by Horst (5) and Michotte (6).

As indicated in Table 2, the quantity of fiber per plant gradually

TABLE 1.—*Relative changes in root, stem, leaf, fiber, and moisture content as associated with age of Hibiscus cannabinus plants based on green weight of the plants.*

Date of sample and age of plant	Percentage of total plant weight			Fiber content of stems, %	Moisture in stems, %	Plant characteristics
	Roots	Stems	Leaves, flowers, seed capsules			
Oct. 4, 35 days	8.9	56.7	33.5	1.9	87.9	Normal and green
Oct. 13, 44 days	9.4	58.4	32.3	2.7	85.1	Normal and green
Oct. 20, 51 days	8.5	59.3	32.4	3.1	82.2	First blossoming
Oct. 27, 58 days	7.0	59.6	33.4	4.6	78.6	2% plants blossoming
Nov. 3, 65 days	7.2	60.0	32.7	5.5	75.1	30% plants blossoming
Nov. 10, 72 days	6.7	59.5	33.7	5.5	72.9	All plants blossoming; lower leaves dropping; stems turning yellow
Nov. 17, 79 days*	7.9	53.8	38.3	5.2	76.5	End of blossoming; many leaves dropped
Nov. 24, 86 days	7.9	60.0	32.0	5.4	72.9	Stems yellow
Dec. 3, 95 days	8.6	67.6	23.4†	5.4	73.7	All leaves dropped; lower seed capsules mature
Dec. 10, 102 days	11.7	67.7	20.5†	5.6	72.8	Many seeds mature; 6 to 8 seed capsules per plant

*Samples were collected during a rain which introduced some error.
†Seed capsules only.

increased along with increases in plant height until November 10 when all plants were in blossom. Likewise, there was a similar increase in the yield of fiber per acre. Although the fiber produced per plant was approximately the same at each sampling from November

TABLE 2.—*Average height of plant, yield of fiber per plant, and yield of fiber per acre from plants harvested at weekly intervals.*

Date of sampling	Average height of plant, in.	Fiber per plant, grams	Yield per acre, lbs.
Oct. 4	28.2	0.3	138
Oct. 13	38.3	0.7	328
Oct. 20	43.7	0.8	472
Oct. 27	53.3	1.4	869
Nov. 3	57.4	1.8	950
Nov. 10	61.1	2.1	927
Nov. 17	62.0	1.9	771
Nov. 24	62.5	2.1	956
Dec. 3	62.9	2.2	1,059
Dec. 10	63.2	1.9	835

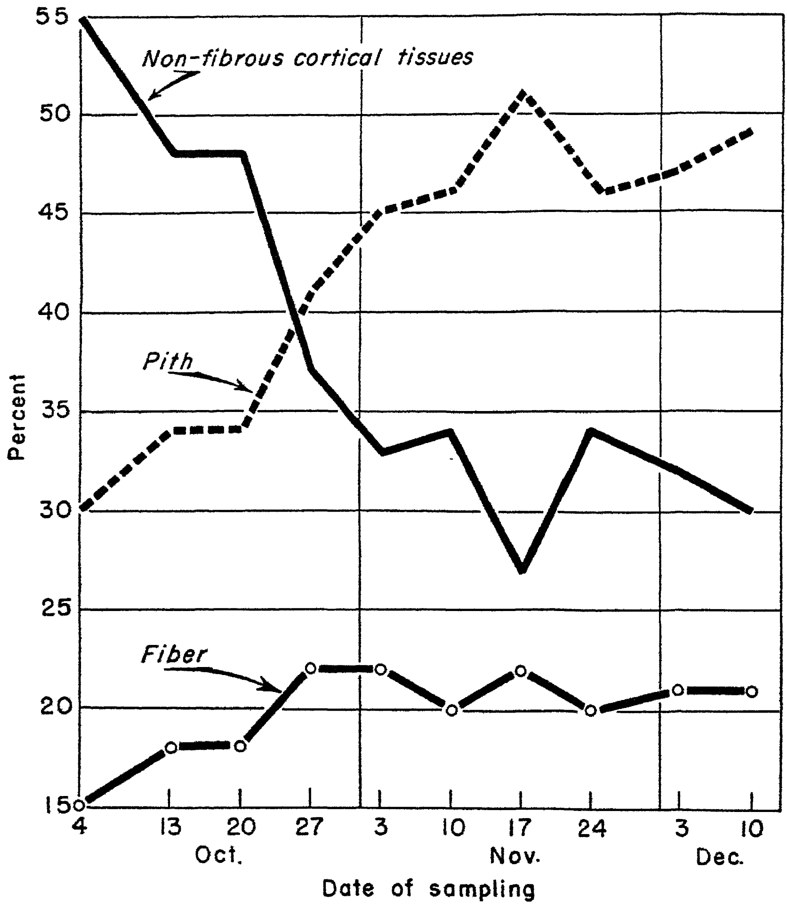

FIG. 2.—Relative composition (dry weight basis) of kenaf stems harvested 1 month after germination and at weekly intervals thereafter until seed maturity. Sampling on November 17 was done during a rain.

10 to December 10, the yield of fiber per acre varied somewhat. This variation, however, was due to the variability in plant stand. In thinning the plants after germination, an attempt was made to space the plants about 1½ inches apart in the row so that each sample would contain the same number of plants. Actually, however, the average distance between plants in the various samples ranged from 1.2 to 1.7 inches which in all probability caused the variation in yield.

DISCUSSION AND CONCLUSIONS

The authors wish to point out the fact that the yield of fiber data presented in Table 2 should not be considered as being representative of the yield which can be expected from this plant when planted and grown during the time of year best suited for its production. The

yields were very low for three reasons. First, the soil in which these plants were grown was of low fertility due to the way it had been cropped. For several years previous to this experiment, the land had produced two or three hay crops each year which resulted in the serious depletion of soil nutrients. Second, the soil was infested with nematodes to the extent that half of the experiment had to be abandoned. Although the plants on which data here reported were obtained suffered only mild attacks from nematodes, growth was nevertheless restricted to some extent by the effect of nematodes on the roots. Third, as mentioned previously, the plants were planted about 4 months too late for maximum yields of fiber per acre.

As kenaf was a newly introduced plant in Cuba, little was known about its cultural requirements until the close of this season when the data of various experiments had been tabulated and analyzed. Observations have shown that for maximum fiber production per unit of land, planting should be done at the beginning of the rainy season which occurs in April or May. Planting at this time enables the plant to grow vegetatively to a height of 10 to 12 feet by the latter part of September at which time flowering begins. As previously mentioned, planting for this experiment was done on August 24. Consequently, the plants had only about 6 weeks for vegetative elongation before flowering started. It is obvious, therefore, that much larger yields of fiber per unit of land can be obtained from this plant than the yields reported in Table 2. Experiments have also shown that planting for fiber should be in rows closer than 20 inches, the distance used in this experiment. By narrowing the distance between rows, greater yields of fiber would be obtained than is reported in this paper.

The question might be asked as to why Horst (5) obtained between 1.66 and 2% fiber from plants which were harvested 97 days after planting, while plants of the same age in this investigation were practically mature and yielded 5.4% fiber. This is easily explained by the fact that kenaf is markedly responsive to length of day (photoperiodism) and at this latitude (about 23° N) flowering takes place about the first of October regardless of planting time during the rainy season. Although Horst has made no reference to day length nor time of planting, it must be assumed from the photoperiodic response of this plant that his plantings were made when the day length was sufficiently long to promote vegetative growth for a period of 4 months or more due to the fact that when the plants were 97 days old they "still had all their leaves and were very full of sap". Therefore, the plants from which he derived his data were about half-way through their vegetative cycle, while plants of the same age reported in this investigation had flowered and matured seed due to the shorter days of September and October. Thus, by planting at a particular time during the rainy season, the plant has a corresponding number of days to complete its life cycle. For example, plantings made on the first of May have 5 months, or until the latter part of September, for vegetative growth, but those made on the first of July have only 3 months in which to grow vegetatively. All of the developmental stages that occur in early plantings are present in

later plantings, but in the latter case these stages occur much more rapidly.

It has been claimed that two, and as many as four, crops of fiber can be grown on the same land in one year. From data obtained in this investigation, however, it is doubtful that more than one crop can be grown on the same land in a year. As the percentage of fiber in the stem does not reach its maximum until flowering, harvesting the plants before that time would not be advisable. Although favorable yields of fiber might be obtained by harvesting the plants before the flowering stage is reached, all evidence points to the fact that the highest quality fiber is obtained when the plants are in blossom. Investigations by Watt (8) and the Imperial Institute (1) both show that fiber harvested during the flowering period is superior to fiber harvested either before or after flowering.

Although quality tests were not made on the samples of fiber obtained in the Cuban experiments, certain characteristics of the fiber and its ease of separation from the pith were noted. With an increase in age of the plant there appeared to be an increase in coarseness and a decrease in lustre of the fiber. With the first formation of seed capsules on the stems, the fiber adhered to the pith more firmly than fiber in plants harvested earlier. The tendency of the fiber to adhere to the pith apparently increases with the age of the plant. This phenomenon, together with the decrease in moisture percentage of the stems, might explain why it was practically impossible to decorticate, in henequen decorticating machinery, kenaf plants that had reached the seed-pod stage, while plants which had not reached the stage of seed pod development were decorticated satisfactorily.

SUMMARY

In order to trace the development of fiber in kenaf stems, observations were made at the Cuban Agricultural Experiment Station with respect to the percentage of various component plant parts in addition to morphological appearance of the plants.

Data were collected periodically throughout the life cycle of the plant and the results are expressed in tables and graphs. Developmental changes in the various characters from week to week, as well as their interrelationships, are discussed.

The conclusion reached is that kenaf for fiber should be harvested during the flowering stage in order to obtain best results as far as yield and separation of the fiber from the stem is concerned.

LITERATURE CITED

1. Anonymous. The Cultivation of jute and similar fibres. Imp. Inst. Bul. 3: 251–262. 1905.
2. Dekker, J. F. Java-jute en roselle. Landbouw, 9:507–513. 1934.
3. El Kilany, M. A. Jute and kindred fibres in Egypt; research and culture. Egypt Min. Agr. Tech. and Sci. Serv. Bul. 215. 1939. (In Arabic with English summary.)
4. Gorkom, K. W. van. Dr. K. W. van Gorkom's Ocst-Indische cultures, opnieuw uitgegeven onder redactie van H. C. Prinsen Geerligs. Amsterdam: J. H. de Bussy. 1913.
5. Horst, W. Adolf. Studien uber den Gambohanf. Faserforschung, 4:61–124. 1924.

6. MICHOTTE, FELICIEN. Les Hibiscus (Ketmie). Traite Sci. et Indus. des Plantes Textiles, Bul. Nos. 3-6. 1928.
7. POPOVA, G. M. A contribution to the morphology and biology of *Hibiscus cannabinus* L. Bul. Appl. Bot., 19:493-496. 1928.
8. WATT, SIR GEORGE. A dictionary of the economic products of India, London and Calcutta: W. H. Allen & Co. 1889-96.
9. ZEGERS RYSER, W. A. Cultuur en bereiding van Hibiscus cannabinus. Vezelcong. gehouden te Soerabaia van 3 tot 8 Juli, 1911. Verslag, deel 1,1. gedeelte, 1911. (Pages 317-328.)

BORON SUPPLY IN RELATION TO CARBOHYDRATE METABOLISM AND DISTRIBUTION IN THE RADISH[1]

P. N. SCRIPTURE AND J. S. McHARGUE[2]

PREVIOUS work by the authors and others (4, 6)[3] has shown that normal carbohydrate metabolism in the growing plant is contingent on the presence of adequate supplies of available boron in the growth substrate. The experiment described in this paper was planned to study the effect of various levels of boron fertilization on the distribution of carbohydrates in the tops and bulbs of the radish plant.

PLAN OF THE EXPERIMENT

Radishes of the Early Scarlet Globe variety were grown in sand culture in the greenhouse, using the continuous drip technic devised by Shive and Robbins (5) for application of the nutrient solution. Two-gallon glazed earthen jars were filled to within 1 inch of the top with purified sand and 10 radish seeds planted in each. The continuous drip apparatus was set up and the sand kept moist with distilled water until the seeds germinated and the first true leaves began to form. At this time the plants were thinned until five seedlings of uniform size and vigor remained in each culture and the application of nutrient solution was started.

The nutrient solution used was the same as that described in a previous paper (3). Boron was supplied to the nutrient solution as boric acid at the following rates:

Culture No.	Boron added to nutrient solution, p.p.m.
1 and 2	0.00
3 and 4	0.25
5 and 6	0.50
7 and 8	1.00
9 and 10	5.00

Each culture received approximately 1,000 cc of the nutrient solution each 24 hours and all cultures were flushed out with distilled water twice each week.

Symptoms of boron deficiency appeared in cultures 1 and 2, 17 days after planting the seed. The first symptom was the appearance of an abnormally dark green color in the surface of the newly formed terminal leaves. This symptom was followed by a roughening of the leaf surface and a tendency of the edges of the leaf to curl in toward the center of the leaf.

A slight browning of the edge of the oldest leaves of the plants receiving 5.00 p.p.m. of boron indicated a boron toxicity. This was not sufficiently serious to cause the death of the plants.

SAMPLING

The plants were harvested 25 days after planting. All five plants from each culture were combined to form a sample. All plants except those not receiving boron had formed normal bulbs. The bulbs of the "no boron" plants were small and the surfaces were badly cracked and roughened. The plants were washed with distilled water to remove sand and wiped to remove excess moisture. The tops and bulbs were then separated and the tops cut into small pieces, placed in weighed Erlenmeyer flasks, weighed, and then treated with boiling 95% ethyl alcohol. Subsequent extractions with 80% alcohol were made as described in a previous

[1]Contribution from the Department of Chemistry, Kentucky Agricultural Experiment Station, Lexington, Ky. The investigation reported in this paper is in connection with a project of the Kentucky Agricultural Experiment Station and is published by permission of the Director. Received for publication January 29, 1945.

[2]Assistant Chemist and Head of Department, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 364.

publication (3). The bulbs were sliced into thin sections, weighed, and then treated with 95% alcohol and extracted with 80% alcohol in the same manner as the tops.

CHEMICAL ANALYSIS OF ALCOHOLIC EXTRACTS

Direct reducing sugars and total reducing sugars after hydrolysis with invertase were determined on all the extracts. Methods of analysis used were essentially the same as those outlined by Phillips and Smith (1) and Phillips (2).

CHEMICAL ANALYSIS OF ALCOHOL-INSOLUBLE PORTIONS

Reducing sugars after hydrolysis of a portion of the residue with H_2SO_4, according to the procedure of Phillips and Smith (1), were determined on all samples.

RESULTS

The yields of fresh plant material are presented in Table 1.

TABLE 1.—*Yield in grams of fresh plant material.*

Boron added in p.p.m.	Tops		Bulbs	
	Yield per culture	Mean of duplicates	Yield per culture	Mean of duplicates
0.00	11.02	12.19	3.60	3.50
	13.36		3.40	
0.25	29.32	30.44	23.90	23.35
	31.56		22.80	
0.50	30.10	32.09	18.25	22.55
	34.09		26.85	
1.00	23.60	25.75	18.75	17.60
	27.90		16.45	
5.00	28.90	28.45	20.62	21.51
	28.00		22.40	

The results for direct reducing sugars present in the alcohol extracts appear in Table 2. The figures reported are in percentage of the fresh plant tissue.

In Table 3, additional reducing sugars found in the alcohol extracts after hydrolysis with invertase are reported. The results are in percentages of the fresh plant tissue.

Although reducing sugars found after invertase hydrolysis probably were derived from sucrose, this sugar was not identified positively by the analytical procedure used. Carbohydrates other than sucrose that are hydrolized by invertase are not usually present in plant tissue in significant amounts, if at all.

TABLE 2.—*Percentage of direct reducing sugars found in alcohol extracts.*

Boron added in p.p.m.	Tops		Bulbs	
	% sugars	Mean of duplicate cultures	% sugars	Mean of duplicate cultures
0.00	0.768 0.430	0.599	0.363 0.397	0.380
0.25	0.129 0.093	0.111	1.695 1.670	1.682
0.50	0.093 0.079	0.086	1.672 1.840	1.756
1.00	0.077 0.075	0.076	3.136 3.295	3.216
5.00	0.092 0.069	0.080	1.786 —*	1.786

*Extract accidentally lost.

TABLE 3.—*Additional reducing sugars found in alcohol extracts after invertase hydrolysis.*

Boron added in p.p.m.	Tops		Bulbs	
	% sugars	Mean of duplicate cultures	% sugars	Mean of duplicate cultures
0.00	0.312 0.215	0.264	1.102 1.677	1.390
0.25	0.088 0.072	0.080	0.381 0.308	0.344
0.50	0.089 0.072	0.080	0.444 0.259	0.352
1.00	0.063 0.057	0.060	0.464 0.483	0.474
5.00	0.070 0.048	0.059	0.269 —*	0.269

*Extract accidentally lost.

In Table 4, the reducing sugars found after hydrolysis of the alcohol-insoluble residue with normal H_2SO_4 are reported. The figures are percentages of the fresh plant tissue.

Though no particular group of compounds is identified by this procedure, the results do give some information in regard to the

amounts of the storage forms of carbohydrates present. The results, without doubt, include starches if they are present and some of the other less resistant polysaccharides.

TABLE 4.—*Reducing sugars found after acid hydrolysis of alcohol-insoluble residue.*

Boron added in p.p.m.	Tops		Bulbs	
	% sugars	Mean of duplicate cultures	% sugars	Mean of duplicate cultures
0.00	0.161	0.144	0.133	0.204
	0.126		0.276	
0.25	0.136	0.106	0.080	0.082
	0.076		0.083	
0.50	0.082	0.080	0.087	0.075
	0.079		0.063	
1.00	0.045	0.056	0.080	0.091
	0.067		0.102	
5.00	0.086	0.074	0.100	0.091
	0.062		0.082	

DISCUSSION

An examination of the yield data presented in Table 1 indicates that, under the conditions of this experiment, a concentration of somewhere in the range of 0.25 to 0.50 p.p.m. of boron in the nutrient solution as measured by yield of tops and roots is optimum for radish production. As mentioned previously, 5.0 p.p.m. were slightly toxic and reduced the fresh weight of tops and bulbs produced to a small though not significant degree. No noticeable difference in quality of the bulbs was evident in any of the cultures receiving boron, regardless of the amount.

The data presented in Tables 2, 3, and 4 indicate that the metabolism and distribution of carbohydrates is significantly altered by a deficiency of boron. Direct reducing sugars, sugars hydrolized by invertase, and alcohol-insoluble carbohydrates hydrolized by normal H_2SO_4 were found present in excessive amounts in the tops of plants grown without added boron. The amount of boron added appeared to have little effect on these constituents as long as enough was present for normal growth.

The radish bulbs that were grown under boron-deficient conditions contained excessive amounts of sugars hydrolized by invertase and alcohol-insoluble, acid-hydrolizable carbohydrate, but they contained less direct reducing sugars than did the plants receiving boron in the nutrient solution. Apparently the radish growing under normal

conditions accumulates carbohydrate in the form of direct reducing sugars.

From these results it seems that boron must be functional in the metabolism and translocation of carbohydrates. Whether this function is direct or indirect through its effect on nitrogen metabolism cannot be determined with the information at hand.

SUMMARY

1. Radishes were grown in sand culture with boron supplied to the nutrient solution at the rate of 0.00, 0.25, 0.50, 1.00, and 5.00 p.p.m.

2. Yields of the radishes were determined and the tops and bulbs analyzed separately for soluble and insoluble carbohydrates. A concentration of 0.25 to 0.50 p.p.m. of boron in the nutrient solution appeared to be optimum for the radish.

3. A deficiency of boron was found to cause an accumulation of direct reducing sugars, sugars hydrolized by invertase, and alcohol-insoluble acid-hydrolizable carbohydrates in the tops, and an accumulation of sugars hydrolized by invertase and alcohol-insoluble acid-hydrolizable carbohydrates in the bulbs. Direct reducing sugars were found to be lower in the bulbs of the boron-deficient plants than in those receiving the required amounts of this element.

4. From these results it seems that boron must be functional in the metabolism and translocation of carbohydrates.

LITERATURE CITED

1. PHILLIPS, T. G., and SMITH, T. O. Composition of timothy. N. H. Agr. Exp. Sta. Tech. Bul. 81. 1943.
2. ————. Semimicro method for determining copper reduced by sugars. Jour. Assoc. Off. Agr. Chem., 24:181–182. 1941.
3. SCRIPTURE, P. N., and MCHARGUE, J. S. Effect of boron concentration in the nutrient solution on the soluble and insoluble nitrogen fractions of spinach. Jour. Amer. Soc. Agron., 36:865–869. 1944.
4. ————, ————. Effects of boron deficiency on the soluble nitrogen and carbohydrate content of alfalfa. Jour. Amer. Soc. Agron., 35:988–992. 1943.
5. SHIVE, J. W., and ROBBINS, W. R. Methods of growing plants in solution and sand culture. N. J. Agr. Exp. Sta. Bul. 636. 1940.
6. WADLEIGH, C. H., and SHIVE, J. W. A microchemical study of the effect of boron deficiency in cotton seedlings. Soil Sci., 47:33–36. 1939.

NATURAL CROSSING IN SUDAN GRASS[1]

R. J. Garber and S. S. Atwood[2]

THE extent of natural crossing within a plant species is of direct importance in developing effective breeding methods. Such information about sudan grass, *Sorghum vulgare* var. *sudanense* (Piper) Hitchc., is somewhat limited, although considerable data have been reported on other cultivated varieties of the species *S. vulgare*. The earlier literature has been reviewed by Hayes and Garber.[3] In most cases the natural crosses observed among sorghums were less than 10%.

In studies at Madison, Wis., Hogg and Ahlgren[4] used a recessive glossy leaf character to determine the extent of natural crossing in sudan grass. The 870 plants involved were grown in alternate rows and open-pollinated seed was harvested from the plants possessing the recessive character. Counts made on the seedlings from the several rows showed 4.8, 5, 9.4, 4.5, 8.2, 3, 7.6, 6.6, 10, and 7.7% plants with the dominant character. The mean percentage was 6.7.

The presence of tan and red[5] pigmented selfed strains of sudan grass in the breeding nursery at State College, Pa., together with the fact that tan behaves as a simple recessive to red in inheritance[6] provided an opportunity to determine the extent of natural crossing.

MATERIAL AND METHODS

The strains of sudan grass used in this investigation had been selfed from 2 to 4 years after their introduction into the local nursery, and some of them were introduced as selfed strains. All of the tan-pigmented strains came from material descendant from crosses between Leoti sorghum and sudan grass made and furnished by the courtesy of R. E. Karper and J. R. Quinby of the Texas Agricultural Experiment Station. The 12 red-pigmented strains came from various sources, but the known lineage of 7 of them goes back to the same material of hybrid origin supplied by the Texas Station.

The general plan of procedure was to grow tan- and red-pigmented strains of approximately the same "heading date" and harvest seed of the recessive tan plants for making a determination of the number of crosses with red plants. It is possible to distinguish between red and tan seedlings of most strains, but since it

[1]Contribution No. 72, U. S. Regional Pasture Research Laboratory, Division of Forage Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture, State College, Pa., in cooperation with the northeastern states. Received for publication January 29, 1945.

[2]Director and formerly Associate Agronomist, respectively. The latter is now Assistant Professor of Plant Breeding, Cornell University, Ithaca, N. Y.

[3]Hayes, H. K., and Garber, R. J. Breeding Crop Plants. New York: McGraw-Hill Book Co., Inc. Ed. 2. 1927.

[4]Hogg, P. G., and Ahlgren, H. L. Environmental, breeding, and inheritance studies of hydrocyanic acid in *Sorghum vulgare* var. *sudanense*. Jour. Agr. Res., 67:195–210. 1943.

[5]No effort was made to distinguish between black-or-straw glume color (blackish-purple plant color) and red glume color (red plant color) or between chocolate glume (tan plant color) and sienna glume (tan plant color), but all plants were classified on the basis of color of leaf "spots" as reported earlier by Garber and Chilton (footnote 6). The basis of color classification might be more accurately described as tan and nontan.

[6]Garber, R. J., and Chilton, S. J. P. The occurrence and inheritance of certain leaf "spots" in Sudan grass. Jour. Amer. Soc. Agron., 34:597–606. 1942.

is easier to make the distinction after the plants have attained considerable growth all the determinations reported here were made in the nursery when the plants had reached the "boot" stage of development.

A small quantity of seed was collected in the nursery in 1941 for some preliminary observations and seed for the 1942 and 1943 tests came from crossing blocks. The 1941 strain numbers are used throughout because seed for the crossing blocks came from the 1941 nursery. Since the details of procedure varied somewhat in the different years, it will be more convenient to present them in connection with the discussion of results.

RESULTS

1941

By chance a red and a tan strain with approximately the same pollination period occurred in adjacent rows in two locations in the sudan grass nursery in 1941. The adjacent rows were 5 feet long and 30 inches apart with about 20 plants spaced along each row. Toward the latter part of the pollination period panicles about ready to dehisce were bagged in pairs, one from a red with one from a tan plant. Owing to a storm and other natural hazards only a few bagged seeds from one of the tan strains were obtained. However, a single open-pollinated panicle was harvested from each of the two tan strains.

Of 183 progeny from a tan panicle (strain 297) bagged with a red one (strain 296), 111, or 60.7%, proved to be red. Seed from the open-pollinated panicle of the same tan strain produced 31 plants of which 24, or 77.4%, were red. The other tan strain (358) occurred adjacent to one (357) segregating for color, approximately three-fourths of the plants being red. From an open-pollinated panicle of this tan strain, 41 plants were obtained of which 31, or 75.6%, proved to be red. These data, although very meager, indicated that the incidence of natural crossing in this material was high.

1942

Tan and red strains were grown in close proximity in a partly isolated crossing block in 1942. An attempt was made to alternate tan and red plants with similar maturity dates at intervals of about 1 foot along a single 18-foot row. Owing to loss of stand, this arrangement was only approximated in the final stands. The rows containing the different paired strains were 1 foot apart. In all, five paired strains were planted but owing to an early frost adequate seed for a test was obtained from only two of them.

The total number of progeny from the tan strains and the percentage of red plants (percentage of crossing with red parents) are shown in the last two columns of Table 1. The percentage crosses, 14.9 and 27.8, are considerably less than were obtained previously. Out of a total of 676 progeny from tan plants, 123, or 18.2%, were crossed with red plants.

1943[7]

The 1943 crossing block was effectively isolated from other sudan grass and contained 14 strains again paired on the basis of plant

[7]The authors are indebted to K. W. Brown and E. J. Dollinger for help in classifying the plants and analyzing the data.

TABLE 1.—*Natural crosses in a partly isolated block of sudan grass, 1942.*

Paired red and tan strains	Total progeny of tan strains	Percentage crossed with red
50, 27	497	14.9
39, 76	169	27.8
120, 112	10	20.0
Total..............	676	18.2

color and maturity dates. A tan strain was planted between two rows of the red strain with which it was paired. The rows were 18 feet long and 18 inches apart with 100 seeds spaced along each row. The rows were planted approximately crosswise to the prevailing wind. At about weekly intervals during the flowering period different colored tags to designate different maturity dates were fastened to flowering tan panicles that at the time were well surrounded with similarly flowering red panicles. Progeny tests of tan seed from the four pollination periods were analyzed separately as indicated in Table 2.

TABLE 2.—*Natural crosses in an isolated block of sudan grass, 1943.*

Paired red and tan strains	Total number of progeny tested and percentage crosses at various periods				Mean
	Aug. 6	Aug. 12	Aug. 19	Aug. 26	
233, 95	168 26.8	196 38.8	169 19.5	144 38.9	31.0
71, 65	169 24.3	170 37.0	207 38.2	151 56.3	39.0
93, 358	208 22.6	209 30.1	213 51.6	98 70.4	43.7
25, 62	8.2*	237 22.8	213 16.4	112 39.3	21.7
302, 66	218 16.0	202 21.3	203 31.0	97 51.5	30.0
13, 88	32.5*	175 46.8	204 48.0	157 56.7	46.0
Mean	21.7	32.8	34.1	52.2	34.4
136, 59				79 17.7	

*Calculated.

The analysis of variance of the progeny is shown in Table 3. The mean squares for pollination periods and for strains are both significantly greater than for error, yielding respective F values of 13.83

and 5.00 which are beyond the 1% level of significance. Under the conditions of this experiment the incidence of natural crossing increased during the flowering period and differed significantly between strains. Of the 3,999 plants grown from the 1943 crossing block, 1,374, or 34.4%, were red.

Climatological data collected at State College, Pa., for August 1943 did not reveal any striking departures from normal conditions that might be associated with incidence of natural crossing. The rainfall, which was well distributed, totaled 3.08 inches for the month, a departure of −0.4 inch based on a 59-year average. There were 8 clear days, 13 partly cloudy, and 10 cloudy. The highest temperatures occurred around the 12th and the lowest temperatures around the 19th of the month. The mean temperature for August was 70.5°, a departure of +1.7° from the norm.

RESULTS IN TEXAS

The authors are indebted to R. E. Karper, and J. R. Quinby, agronomists of the Texas Agricultural Experiment Station, for the following unpublished data, transmitted in a recent letter: "Our material was progeny rows of Leoti-sudan crosses of similar parentage as yours. In 1942 we had progeny rows planted from open-pollinated seed in which the outcrosses were harvested separately and recorded. The stock was juicy and had sienna glume, so that the outcrosses were identified either by their pithy stem or by having some glume color other than sienna. Each of nine progeny rows showed the following percentages of cross pollinations: 50, 70, 30, 72, 43, 60, 15, 30, 40, respectively. Eleven other progeny rows showed the following percentages: 7, 37, 47, 43, 50, 17, 20, 40, 20, 23, 37. The average in the first case was 46% and in the second set of progeny rows it was 31%; the maximum in one row was 72%, very close to the 76% maximum which you obtained."

TABLE 3.—*Analysis of variance of incidence of natural crosses in sudan grass with respect to selfed strains and pollination periods.*

Source of variation	Degrees of freedom	Sums of squares	Mean squares	F
Total	21	5478.86	—	—
Pollination periods	3	2860.31	953.44	13.83**
Strains	5	1722.62	344.52	5.00**
Error	13	895.93	68.92	

**Beyond the 1% level of significance.

SUMMARY AND CONCLUSIONS

Data collected over a period of 3 years are presented that indicate the incidence of natural crossing among the particular selfed strains of sudan grass under observation at State College, Pa., was highly variable. Significant differences were found with respect to strain and season. The fact that all the tan strains tested had a common hybrid origin (Leoti sorghum × sudan grass) may in part explain the generally higher incidence of natural crossing than reported else-

where. Owing to the limited selfed seed, identical tan strains were not tested in different years except in one instance. Strain 358 which showed the highest incidence of crossing (70.4) in 1943 (Table 2, August 26) showed 75.6% in 1941. The average percentages of crosses between tan and red plants grown near one another as measured by progeny of the tan plants were for the years 1941, 1942, and 1943, 76.4, 18.2, and 34.4, respectively.

The results reported here, as well as those reported from the Texas Agricultural Experiment Station, indicated that the incidence of natural crossing was significantly greater in this material than has been reported for sorghum. This suggests that in seeking to develop improved strains by breeding, hybrid vigor may be more readily utilized in the commercial variety of sudan grass than in that of sorghum.

A COMPARATIVE STUDY OF METHODS FOR DETERMINING YIELDS OF KENTUCKY BLUEGRASS AND WHITE CLOVER WHEN GROWN IN ASSOCIATION[1]

V. G. SPRAGUE AND W. M. MYERS[2]

IN A field plot experiment designed to measure the relative yields of 15 strains of Kentucky bluegrass when grown in association with white clover and simultaneously to study the effects of different grass strains, clipping treatments, and environmental factors upon the incidence of white clover, it was necessary to determine accurately the amount of clover and of Kentucky bluegrass growing on each plot. The point quadrat devised by Levy and Madden (4)[3] and modified by Tinney, Aamodt, and Ahlgren (7) has been used extensively for this purpose. However, Arny and Schmid (1) reported that with certain plant associations the results obtained from the inclined point quadrat were not the same as those obtained from botanical separations of associated species. Drew (2) has shown with studies on a lespedeza-panicum association a close agreement between the average of 20 inclined point quadrat determinations and the average of a similar number of weight analyses of herbage clipped at ground level from the same areas. Preliminary results obtained in our experiments seemed to agree with Arny and Schmid (1). Therefore, it was desired to check the accuracy of the point quadrat method before extensive use of it was made in the experiment being conducted.

An accurate measure of botanical composition would be obtained by separating the several species in the herbage clipped from the entire plot. Separation is, however, a laborious and time-consuming procedure especially when large samples are involved. Herbage harvested with a lawn mower is particularly difficult to separate, yet the lawn mower provides a simple and easy method for harvesting yield samples from plots of Kentucky bluegrass. To reduce the amount of herbage to be separated and to overcome the difficulties of handling lawn mower clippings, a method of sampling for botanical composition using grass shears was employed.

This paper reports the results of sampling studies to determine the size of sample required to estimate accurately the botanical composition of the plot. A comparison of the separation method with the point quadrat method also has been made.

MATERIAL AND METHODS

For use in this experiment, 13 strains of Kentucky bluegrass were selected from those previously reported by Myers and Garber (5). In addition, two commercial seed lots were included as checks. Two clipping treatments were used. For one treatment (from which all the data here reported were obtained), the

[1]Contribution No. 70, U. S. Regional Pasture Research Laboratory, Division of Forage Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture, State College, Pa., in cooperation with the northeastern states. Part of this paper was presented at the annual meeting of the Society in St. Louis, Mo., November 12, 1942. Received for publication January 29, 1945.

[2]Agronomist and Geneticist, respectively.

[3]Figures in parenthesis refer to "Literature cited", p. 377.

plots were clipped with a reel-type mower to 1 inch throughout the season, while in the other, the clipping height was ½ inch during the spring and early summer and 1 inch after July 1. All plots in each treatment were clipped when the height of herbage ranged from 4 to 5 inches.

A split plot design with four replications was used, the clipping treatments being the main plots and the grass strains the sub-plots. Each sub-plot was 3 feet wide and 9 feet long. The plots were seeded in the fall of 1940 and at that time a uniform seeding of white clover was made over the entire area. The clover seeding was repeated in the spring of 1941. Because of the unfavorable winter and dry summer of 1941, little clover appeared in these plots until fall. The clover distribution was very uneven in the spring of 1942, but the proportion of clover increased rapidly during the summer, and with this increase, the distribution became progressively more uniform. All plots were clipped uniformly several times during 1941 and no yields were taken.

Differential clipping treatments were started in the spring of 1942. For the sampling study reported in this paper, only the plots clipped at 1 inch throughout the season were used. For estimating the botanical composition of the herbage removed, each plot was sampled with grass shears by clipping three narrow strips, each about 2 inches wide parallel to the long axis of the plot. To locate these strips, the yield strip (a swath the width of the power lawn mower) was divided longitudinally by estimation into three parts and one sample was taken at random within each part. As a guide for cutting the sample strips, a string was stretched through the plot for each sample. At the first cutting date, the entire strip was clipped in each case. Since this provided a larger sample than was desired, samples approximately one-half as large were obtained at the last three dates by alternate cutting and skipping approximately 4-inch lengths along the sample strip.

The fresh samples were separated in the laboratory into Kentucky bluegrass, white clover, and other species (mostly weeds), the samples were dried, and all weights were recorded as oven-dry material. The percentage of weeds was negligible in these plots. All data reported in this paper deal with percentages of white clover.

Data were taken with the inclined point quadrat the day before the clipping of June 23 and 3 days before the clipping of October 19. In each plot, readings were taken at three stations with 10 needles per station. The plots were divided by estimation into three parts and location of the station in each part of the plot was at random. All of the vegetative hits by each needle until it reached the ground or went out of sight were recorded and the proportion of clover was considered to be the percentage of the vegetative hits that were clover.

EXPERIMENTAL RESULTS

The analysis of variance of the percentage of white clover based upon species separation is summarized in Table 1 for the four clipping dates. It may be seen that the error variance was higher for July 21 than for June 23, while that for September 3 and especially October 19 is lower than for the other cutting dates. A similar relationship exists for the variance within plots, i.e., for the sampling variance. There was a considerable increase in amount of white clover throughout the season from June 23 to October 19. Also, the sample was larger in relation to yield of the plot in the first clipping than in the latter three. Ordinarily one would expect an increased error variance with an increased mean and smaller samples. Instead, the variance decreased on September 3 and still more at the last cutting date. This probably resulted from the greater uniformity of the clover stand as the amount of clover increased.

The relationship of the error mean square to the variance within plots is of primary importance in determining the accuracy of the sampling method. It may be seen (Table 1) that the F values for this comparison are approximately the same for the several dates of clip-

ping, despite the fact that the samples were relatively almost twice as great at the first date as on July 21 and September 3. This indicates that there was less variation within plots at the latter two dates, probably as a result of the increased uniformity of the clover stand mentioned previously.

TABLE 1.—*Analysis of variance of the percentage of white clover, and the mean percentage of clover as measured by botanical separation, and the relative size of sample used for the four dates of clipping.*

Variance due to	D/F	Dates of clipping							
		June 23, 1942		July 21, 1942		Sept. 3, 1942		Oct. 19, 1942	
		Mean square	F	Mean square	F	Mean square	F	Mean square	F
Blocks.. ...	3	1,094.0	—	1,309.8	—	1,114.3	—	599.9	—
Strains.....	14	614.1	2.56*	974.3	3.10**	454.8	2.22*	213.9	4.51**
Error.......	42	239.8	9.08**	314.2	9.19**	204.8	8.18**	47.4	3.14**
Within plots	120	26.4	—	34.2	—	25.0	—	15.1	—
Mean percentage of clover.......		17.1		29.6		57.1		68.3	
Size of sample in percentage of yield of the plot		20.7		12.4		12.4		16.2	

*Exceeds 5% point.
**Exceeds 1% point.

It has been pointed out by Immer (3) and others that the error mean square consists of two parts, *viz.*, (a) the sampling variance, i.e., variance within plots, and (b) the true variance between plots within replications. This relationship as expressed by the equation

$$K = \frac{np + q}{Nn}$$

where K = the variance of the mean for error; p = the estimated true variance between plots within replications, i.e., in this trial, the error mean square minus q/3; q = the sampling variance, i.e., the variance within plots; n = number of samples per plot; N = number of replications.

It is apparent from the data in Table 1 that at all clipping dates the value of p was relatively great compared with q. Since only the sampling error q is reduced by increased numbers of samples while both p and q are reduced by increased replication, relatively little increased precision may be expected in this material by taking more samples while considerable reduction of experimental error can be obtained by increased replication. This is illustrated in Table 2 in which K has been calculated for three, four, and five replications with various numbers of samples. Thus a single sample per plot with four replications provides greater precision than 10 samples with

three replications. It may be concluded from these results that the method of sampling used provides a relatively accurate measure of the percentage of clover in each plot, even when only a single sample is taken.

From the analysis of variance of the point quadrat data (Table 3) for June 23, an error mean square of 156.3 was obtained as compared with the error variance of 239.8 obtained from the separation analysis, whereas on October 19 the respective variances were 144.8 and 47.4. The variance between stations within plots on June 23 was 71.5 for the point quadrat compared with the sampling variance of 26.4 for the separations, and on October 19 it was 129.8 for the point quadrat compared to 15.1 for the separations. These results indicate that increased numbers of samples per plot will be more effective

TABLE 2.—*Values of K (variance of the mean for error) for percentage of white clover expected from the use of the indicated numbers of replications and samples for the clipping dates.*

Number of		Total samples	Dates of clipping			
Replicates	Samples		June 23, 1942	July 21, 1942	Sept. 3, 1942	Oct. 19, 1942
3	1	3	85.8	112.3	73.8	19.2
3	5	15	78.8	103.2	67.2	15.1
3	10	30	77.9	102.1	66.3	14.6
4	1	4	64.4	84.3	55.4	14.4
4*	3*	12*	59.9†	78.6†	51.2†	11.9†
4	5	20	59.1	77.4	50.4	11.4
4	10	40	58.4	76.6	49.8	11.0
5	1	5	51.5	67.4	44.3	11.5
5	5	25	47.3	61.9	40.3	9.1
5	10	50	46.7	61.2	39.8	8.8

*Number of replications and samples used in this experiment from which the other values of K were calculated.

†Values of K obtained in these experiments; i.e., the error mean square (Table 1) divided by number of replications.

TABLE 3.—*Analysis of variance of the percentage of white clover as measured by the point quadrat and botanical separation methods on June 23 and October 19, 1942.*

Variance due to	D/F	June 23		Oct. 19	
		Botanical separations	Point quadrat	Botanical separations	Point quadrat
		Mean square			
Strains	14	641.1	347.1	213.9	326.9
Error	42	239.8	156.3	47.4	144.8
Within plots	120	26.4	71.5	15.1	129.8
Mean percentage of clover	—	17.1	10.2	68.3	49.8

in reducing experimental error with the point quadrat than in the case with the separations.

Of greater importance for the present study than the relative sampling errors of the two methods is the question whether the point quadrat provides a reliable measure of the contribution of white clover to the yield of the plot. This comparison is shown in Table 4. For all strains, the percentage of clover as measured by the point quadrat was lower than that determined by botanical separations. The average for all strains on June 23 was 10.2 compared with 17.1 and on October 19 was 49.8 compared with 68.3. Furthermore, the differences were not the same for the various strains on either date. The greatest difference on June 23 was 13.05, while the least on that date was 2.66% of clover. On October 19, the greatest difference was 26.0 while the least was 13.4%. The ratios of the values obtained by the two methods were not the same for all strains, the quotients of separation divided by point quadrat varying from 1.31 to 2.93 on June 23 and from 1.25 to 1.68 on October 19. Such great fluctuations seem to preclude the possibility of adopting a generalized correction factor for converting the point quadrat data to the same basis as the botanical separations in this material, and particularly if the amount of clover on the plots is small.

Such great differences between strains suggested a strain effect upon the accuracy of the point quadrat. However, an analysis of variance of the differences between the two methods failed to show a

TABLE 4.—*Percentage of clover per plot measured by the point quadrat and by botanical separation of June 23 and October 19, 1942, for the 15 strains of grass.**

Strain No.	June 23				October 19			
	Method		Difference	Separation divided by point quadrat	Method		Difference	Separation divided by point quadrat
	Separation	Point quadrat			Separation	Point quadrat		
1	23.2	10.2	13.0	2.27	76.3	51.0	25.3	1.50
2	10.6	4.3	6.3	2.47	65.1	46.7	18.4	1.39
3	17.7	11.4	6.3	1.55	69.2	47.9	21.3	1.44
4	15.9	6.4	9.5	2.48	70.9	48.6	22.3	1.46
5	13.0	5.8	7.2	2.24	68.0	47.7	20.3	1.42
6	28.8	20.3	8.5	1.42	67.9	53.6	14.3	1.27
7	16.7	12.7	4.0	1.31	63.7	50.1	13.6	1.27
8	25.0	12.0	13.0	2.08	77.7	61.5	16.2	1.26
9	14.6	10.9	3.7	1.34	65.5	45.5	20.0	1.44
10	28.2	17.6	10.6	1.60	67.9	53.8	14.1	1.26
11	12.0	8.2	3.8	1.46	69.9	47.8	22.1	1.46
12	24.4	18.6	5.8	1.31	64.9	51.5	13.4	1.26
13	8.2	2.8	5.4	2.93	64.3	38.3	26.0	1.68
14	8.5	5.8	2.7	1.46	63.9	47.3	16.6	1.35
15	9.7	5.8	3.9	1.67	69.5	55.5	14.0	1.25
Av.	17.1	10.2	6.9	1.68	68.3	49.8	18.5	1.37

*The figures given for per cent clover by the two methods are the averages of four replications of three samples each.

statistically significant strain effect. The F value for strains/error was 1.64 on June 23 and 0.43 on October 19. F for P of 0.05 with appropriate D/F was 1.97.

Records were kept of the relative time required for determining the amounts of clover by the two methods. Clipping one sample per plot, separating the same into grass, clover, and weeds and weighing each component required an average time of between 34 and 36 man-minutes per plot, whereas the time required to read three stations with the point quadrat required an average of 18 man-minutes per plot. Thus to obtain comparable sampling errors, approximately twice as much time was required by the separation as by the point quadrat method.

In an attempt further to reduce the amount of time required for the botanical separations a study was made of the accuracy of subsampling the sample strip from the plot into quarters for separation rather than separating the entire sample. For this, three samples similar to those regularly taken for the botanical analysis were harvested from duplicate plots of seven different clones. These samples were taken to the laboratory, spread out evenly and uniformly on a large table, and divided into four approximately equal parts. Each part was separated into grass, clover, and weeds and then oven-dried. The percentage of clover of each subsample was calculated. This constituted the determination for a subsample only one-fourth the size of the sample taken from the plot. The greatest difference in the percentage of white clover between subsamples obtained on any plot (four subsamples from each) was 5.95, while the least was 2.26. A statistical analysis of these data are presented in Table 5.

Using the relationship, $K = \frac{n\,p + q}{N\,n}$, between the variance within samples and the true variance between samples within plots, the relative effectiveness of increasing the number of subsamples or of samples can be determined. Since in this case the value of p is relatively great compared with q the value of K (variance of the mean for error) is reduced much more by using more samples per plot than by separating the entire sample (Table 6).

TABLE 5.—*Analysis of variance of the percentage of white clover determined by separating subsamples one-fourth the size of the sample harvested for botanical separations.*

Variance due to	D/F	Mean square	F
Between plots	13	560.7235	11.1**
Within plots	28	51.2890	5.0**
Within samples	126	10.3311	
Mean per cent of clover		70.9	
Sample in per cent of yield		4.5	

**Exceeds 1% point.

No records were kept of the actual time required for subsamplin[g] and separating this quarter-sized sample, but since the actual separa[-] tion of the grass, clover, and weeds required by far the greater pa[rt]

TABLE 6.—*Values of K (variance of mean for error) for the percentage of white clover expected from the indicated numbers of samples and subsamples per plot, sampled October 19, 1942.*

Number of		Total samples	K
Samples	Subsamples		
1	1	1	59.0373
1	2	2	53.8712
1	4	4	51.2890
2	1	2	29.5186
2	2	4	26.9162
2	4	8	25.6445
3	1	3	19.6791
3	2	6	17.9441
3*	4*	12*	16.2354

*The number of samples and subsamples used from which the other values of K have been calculated.

of the time, reducing the size of sample to be separated materially reduced the time required for the determination. While the total time for determining the percentage dry weight of grass, clover, and weeds even by subsampling is still somewhat greater than that required by the point quadrat, the increased accuracy obtainable by the separation method may often be necessary to evaluate the factors under investigation. In the study here being conducted, the critical evaluation of strains and clipping treatments seemed to warrant the additional time required for botanical separations.

SUMMARY

1. Percentages of Kentucky bluegrass and white clover were determined by botanical separations and by the inclined point quadrat in trials of 15 strains of Kentucky bluegrass grown in plots 3 by 9 feet distributed at random in four replications and seeded uniformly with white clover.

2. For the botanical separations, samples were clipped with grass shears before the yield strip was harvested with a lawn mower. At the first clipping date the samples averaged 20.7% of the yield of the harvested strip, while in the other three cuttings the samples averaged between 12.4 and 16.2%.

3. A sampling study showed that the variance within plots was low compared with the estimated true variance between plots within replications. Therefore, it was concluded that the method of sampling provided a reliable measure of percentage of white clover in the plots.

4. Since the error in subsampling was low compared to variability within plots, it was concluded that samples one-fourth the size of the usual samples could be used.

5. Using the inclined point quadrat, the estimated percentage of clover was lower than that found by botanical separations, the general means by the two methods being, respectively, 10.2% and 17.1% on June 23 and 49.8% and 68.3% on October 19. Compared on

the basis of strains, the greatest differences in percentage of clover between the two methods on June 23 was 13.0 while the least difference was 2.7. On October 19 the differences ranged from 26.0 to 13.4% of clover. It was concluded, therefore, that inaccurate results would be obtained from using a constant for correcting the point quadrat data.

LITERATURE CITED

1. ARNY, A. C., and SCHMID, A. R. A study of the inclined point quadrat method of botanical analysis of pasture mixtures. Jour. Amer. Soc. Agron., 34: 238–247. 1942.
2. DREW, W. B. Studies on the use of the point-quadrat method of botanical analysis of mixed pasture vegetation. Jour. Agr. Res., 69:289–297. 1944.
3. IMMER, F. R. A study of sampling technic with sugar beets. Jour. Agr. Res., 44:633–647. 1932.
4. LEVY, B. E., and MADDEN, E. A. The point method of pasture analysis. New Zealand Jour. Agr., 46:267–279. 1933.
5. MYERS, W. M., and GARBER, R. J. The evaluation of individual plants of pasture grasses in association with white clover. Jour. Amer. Soc. Agron., 34:7–15. 1942.
6. SNEDECOR, G. W. Statistical Methods. Ames, Iowa: Collegiate Press, Inc. 1938.
7. TINNEY, F. W., AAMODT, O. S., and AHLGREN, H. L. Preliminary report of a study of methods used in botanical analysis of pasture swards. Jour. Amer. Soc. Agron., 29:835–840. 1937.

A GENERAL LOOK AT THE WEED PROBLEM[1]

M. A. McCall[2]

THE war has brought changes in the weed picture and new problems that must be faced in post-war agriculture. Many of these changes are readily apparent to those who have the responsibility for carrying on weed projects, either research or regulatory, during the war period. Other changes may not now be recognized, but will show up later. The shortage of labor has made it impossible for the farmer not only to maintain the clean-up programs already started, but also to prevent reinfestation of lands once cleared. It is hard to know the total loss in headway resulting from this cause in the Central States, but more than one county weed supervisor has been deeply discouraged on seeing the efforts and productive results from many years' work almost nullified. The shortage of chemicals, especially sodium chlorate, which came just when more chemicals could have been used to make up for the labor shortage, has added to difficulties. Again, the shortage of new machinery has hurt weed programs as it has every other farm activity, though farmers have shown extraordinary ingenuity in getting along with what they have. Correspondingly, in weed control research it has been necessary to curtail all along the line, and it has been possible to keep going only those projects most productive of immediate results and which the research men could carry forward with their own labor.

Another most serious item handicapping weed control has been a general slackening of controls on the dissemination of weed seeds in grain and forage feeds and in seed for sowing. Under the compulsion of feed shortages, scarcities of seed stocks, high prices, and pressure for maximum production, it has been all too easy to persuade most sincere folks to accept almost anything that looked like seed or that had the appearance of a livestock feed. This has been true even of agencies normally expected to guard against such lapses in good agriculture. In some areas, there have been extremely serious results from bringing in low-quality feed grain full of weed seeds, without any regard to the future dangers involved. More than 450 cars of low-grade feed grain badly infested with Canada thistle, quackgrass, and other weed seeds were brought into this country from Canada, and in many cases the grain was fed on farms without grinding or otherwise devitalizing the weed seed. It is difficult to believe that this disregard of our future agricultural welfare was necessary when such feed could have been made innocuous by readily available means, granting as we do that the feed itself was badly needed. The evil consequences of this careless disregard of good agriculture will be felt beyond our lifetimes.

Recognizing the many ways in which the war has affected weed control adversely, one cannot but be impressed, on the other hand,

[1]Presented at the North Central States Weed Control Conference held at Omaha, Nebr., November 16–17, 1944. Received for publication February 1, 1945.

[2]Head Agronomist, in Charge, Division of Cereal Crops and Diseases, and Assistant Chief of the Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture.

by the progress made in all areas in continuing the good fight to bring weeds under control despite discouragement and handicap.

The war, however, in the long-time sweep of events, will soon be history, and there is nothing to be gained by recounting losses resulting from the war except as this may help us to recognize our problems and to plan for the future. The virtual disappearance of bindweed in some counties where it was once abundant is most encouraging, and if we happen to be feeling quite optomistic we might even be able to persuade ourselves that when things clear up it should not take too long to clean up that part of the job. There seems little chance for any such happy ending at an early date. In the first place, bindweed is only one of at least 30 weeds which are truly "noxious", in every sense of the dictionary definition of that word. Not all of these weeds occupy as much land as bindweed has invaded, though at least one of them, Johnson grass, probably occupies an even larger area than bindweed ever did. Some of these weeds, for instance Russian knapweed, white top, and poverty weed, to name a few, seem to be even more difficult to kill than bindweed, and it may take a lot of hard work by our research men to find effective methods that will take less time and effort than present information makes necessary. That would only be repeating our experience with bindweed, however. Altogether, there remain, as nearly as we can estimate, more than 2,000,000 acres of good agricultural land virtually out of production because of noxious weeds. Certainly the job is far from finished when a problem of that magnitude is still on tap.

The interests of this group cover a wide variety of agricultural types. There are distinctive weed problems for practically each one of these types. As an example, most of us probably would think of field weeds as the most serious weed pests of irrigated lands. In some areas they are, but aquatic weeds that grow in ditches and other shallow water are by no means far behind. The Bureau of Reclamation spends more than $100,000 a year dragging weeds out of the irrigation canals and drainage ditches under its jurisdiction, and even with this expenditure considers the job poorly done. The Bureau of Reclamation has supervision over less than one-seventh of the irrigated land in the United States, so the irrigation ditch aquatic weed problem is one of some magnitude. In addition to the irrigation ditch and reservoir aquatic weed problem, there are other aquatic weed problems of public importance. In the bayou country of Louisiana and along the St. John River and elsewhere in Florida incredible masses of water hyacinth block not only minor streams and drainage ditches but navigable streams as well. For 30 years the War Department has waged a losing battle against these pests. The Office of the Chief of Engineers spends upwards of a quarter million dollars each year merely to clear small temporary channels through the weeds so that some navigation of a sort can be maintained. The solution of this problem is a real challenge to ingenuity. City reservoirs, private lakes, dam sites, fish hatcheries, and water supply systems have aquatic weed problems of equal extent and importance. They tie back to the same requirements for control as our farm irrigation water

weed menace and should receive attention from public weed control agencies.

In irrigated sections there are dry land as well as aquatic weed problems. In one of the oldest reclamation projects in the West we are told that one-eighth of the cultivated land has been out of production for a number of years because of white top, morning glory, and similar weeds. Another one-eighth is so badly infested with these weeds that it soon will be added to the total. These lands cost the people of the United States a large amount of money to bring them under water, and hundreds and even thousands of settlers and their families have spent their lives and resources to make what they hoped would be productive farms out of this and similarly infested land. Their lifetime of effort has been wasted in all too many cases because these vicious weeds have not been controlled. Much of the trouble starts and is maintained by ditch bank infestations that no one originally considered himself responsible for. The whole complex of weed infestation on irrigated lands in many cases requires special attention and clear definition of responsibility for effective control, another challenge to both research and control agencies.

Another most serious weed problem is that of brushy shrub-like weeds infesting range and pasture lands throughout the United States. According to our by no means complete records, there are 39 kinds or species of shrubs or small trees, each of which infests some 10,000 acres or more of otherwise good pasture or range land. Some of these infestations run into millions of acres. Examples are mesquite and cedar in Texas; gorse, blackberry, and Scotch broom on the Pacific Coast; saw palmetto along the Gulf Coast; sassafras, persimmon, and buckbrush in the Ozarks and Kentucky; and sage brush and shinnery oak in the breaks of western Oklahoma and adjacent Texas. Altogether, some 5,000,000 acres of land that should be in grass are estimated to be occupied by these worthless shrubs.

The control of weedy shrubs is only a minor phase of the range and pasture weed problem. Pastures have always been a major breeding ground for farm weeds. We are now coming to realize, however, that pastures are an important part of good farm plans and operation, and that to return the profits they are capable of yielding weeds must be controlled. How to control and eliminate the wastes and losses from weed infestations on the some 300,000,000 acres of farm rotation and permanent pastures, let alone the even larger areas of range lands, is a challenge to all of us.

Another segment of the over-all weed problem in which we all have a vital interest is that of weed infestations on highway and railroad rights-of-way. Both of these, if neglected, serve as primary sources for farm infestation. Railroads have been interested in weed control because of the fire and accident hazards from weeds and the generally unsightly appearance of excessive weed growth. They are also conscious of their obligations to their agricultural clientele. Highway maintenance engineers have equally definite reasons for controlling weeds, and are equally conscious of their obligation, but too often do not have means for doing the job. Neither the railroads nor highway officials, however, in spite of the best efforts of their best

engineers have solved their weed problem satisfactorily. Perhaps this is partly due to the fact that they are engineers and approach the job too often as engineers and not as agronomists. It is probably true that they might have greater success with their weeds had they more benefit of advice from men who know the plant side of the problem. Be that as it may, the problem has had attention from a good many able men, and it is by no means solved. The railroads are trying to control weeds on some 300,000 miles of track, using salt, sodium arsenite sprays, sodium chlorate, crude oil, flaming, etc., all of which are expensive and not always too effective, or at best may develop accessory problems such as soil erosion which must be controlled. The railroad and highway officials have a right to expect our assistance, since they pay taxes, and their failure in turn menaces the farmer. All of this raises still another serious problem common to most of the western states. That is how to control weeds on public lands. As time goes on this problem is quite likely to extend to the whole country. It is a challenge to all of us.

A side-line use for herbicides, which some of you may be called upon to service as experts in herbicidal action on plants, has to do with defoliating certain plants to facilitate harvesting operations. Mechanized picking of cotton offers large opportunities to reduce costs. Leaves interfere with operations and increase waste and trash in the picked cotton. By spraying or dusting the cotton plants with an herbicide, the leaves can be killed and removed from the plant, leaving only the bare stalks and the cotton bolls for the mechanical picker to work on. Potato growers in some areas follow the practice of spraying potatoes with an herbicide in advance of harvest to kill the vines. This is done to check the late blight disease, to prevent the over-development of tubers, to permit earlier harvesting at a time of higher prices, or for any of several reasons. Men skilled in destroying weeds with herbicides should be able to render service in this type of herbicidal plant control.

One phase of the over-all weed problem which is badly neglected is that of annual weeds. They, like the poor, are "with us always." No accurate estimate has ever been made of the net cost of damage from annual weeds, but certainly they are far more serious in total than even our most noxious weed species. The very insiduous and ofttimes inconspicuous attack makes them doubly dangerous. Some, adopting a semidefeatist attitude, even argue that at least in some cases annual weeds have certain values and act as Nature's means of conserving the soil. This may be partly true, particularly when we follow poor cropping sequences and neglect adequate soil cover, but there is certainly no merit in propagating worthless weeds merely to lessen the evils of slovenly farming. In most cases such a philosophy leads to a result worse than the sum of the two evils alone. Consider, for example, puncture vine, which in the last 15 years has spread eastward and northward from southern California until in places it covers the earth with its miserable spiny fruits. The world has no conceivable need for puncture vine. Something must be done to control its spread. Downy brome grass has some value for early spring grazing, but by the middle of June it has become a fire menace

of frightening proportions over vast areas in Mountain and Intermountain West. We could do without it. Fanweed certainly costs our farmers an immense sum with no return. We would like to be rid of this pest also. Yet in spite of general agreement that all of these and the many other annual weed pests should be brought under control, no one has yet devised any really effective way to do it. It looks like some of us should tackle the job in earnest.

Obviously, in a short time no one could review even a beginning o the weed problems that confront us. What has been said, however, may serve as a background for considering what can be done about the matter.

We have only to think back to the somewhat apathetic public concern about weeds which existed in 1934 to realize the progress that has been made in the few years since that date. Happily, general public attitudes on weed control now are definitely less passive. Certainly there is a growing weed consciousness, or an improved weed psychology, on the part of farmers and of local, state, and federal officials. It may be expected that improvements in control methods will further implement an even more active public interest. While farsighted individuals have long been aware of the weed menace, it has been little more than a decade since the public began really to be aware of weeds in this country. The good start with encouraging results in both research and control activities gives every reason to expect equal or greater progress in the next 10 years.

While we may be greatly encouraged by improved attitudes and by actual progress in control, we must not lose sight of the fact that final success depends on making weed control an integral part of day to day operations on each and every farm. Research may show how and when to do the job so as to get best results most certainly and most cheaply. Control officers may spark the over-all program and may handle that part of the work that is out of hand or that is a public responsibility. But in the end, continuing control depends on each individual farmer on his own farm. Everything that we do in the development of methods through research or in the organization of control programs should be based on the fact that in the end the farmer must do the job.

Recognizing the part which the farmer must play in weed control, special attention should be given to factors that will help him most effectively. Cultivation and other tillage operations, for example, will always occupy a prominent place in the picture. Great advances have been made in these operations through the use of tractors and larger units, but the principal implements work much the same and our plan of work is much as in our fathers' day. Recent engineering studies suggest that a great deal can be done to streamline some of these rather simple and fundamental operations in a way that can greatly improve their efficiency, may modify the kinds of tillage machinery offered for our use by manufacturers, and in the end change concepts and attitudes toward cultivation on the part of farmers.

Knowing the ingenuity of our people, it would be most surprising if we do not relatively soon have kinds of machinery for weed control that are unknown today. As an example, a flame-throwing machine attached to a tractor has been used successfully to burn the weeds out of young cotton rows at a speed of 5 to 6 miles an hour and without injury to the cotton. The machine also works well in sugar cane, and with adjustments may ultimately prove useful for other crops and situations as well. Some day the blast of the weed burner instead of the clank of the cultivator, may be heard in some parts of our land. Other implements for weed control likewise should be expected.

Associated with the use of improved machinery and mechanical methods should be the use of crops better adapted to weed control, and better crop rotations and sequences working to the same end. The tremendous expansion in soybeans during the war, while it may not be maintained at present high levels, is certain to remain in part. Soybeans properly balanced with other crops will have a definite effect on farm weed control. The almost universal adoption of hybrid corn, with its high yield potentials, tends to encourage better care with better weed control as a corollary result. Better livestock, better crop varieties, all tend to raise the standard of operations, the beautiful stands of uniform corn, for example, rousing the pride of the grower and emphasizing the undesirable presence of cockleburs and ragweeds.

Always there is that pot of gold at the end of the rainbow, some mystic rite that will eliminate the weeds at a wave of the hand, or at most by sprinkling on some magic chemical that will do the job without more ado and without other harmful effects. Since Adam was cast from the Garden of Eden under the Divine sentence that he must earn his daily bread by the sweat of his brow, his descendants have been looking for some way to ease the penalty. In weed control for a time we looked hopefully toward the chlorates, arsenicals, acids, borax, some one or the other, as a possible answer. These have proved useful in certain situations, but each has its limitations and disadvantages, and none of them have removed the sweat or the labor from the main job.

This, however, is no reason for discouragement, nor is it proof of the negative philosophy that fleas are good for a dog or weeds for man. As a matter of fact, the present condition of world affairs suggests that all of us might be better off if our minds were more centered on the fact that we are men rather than otherwise.

In line with the old axiom that it is always darkest just before the dawn, there is some reason to believe that we may actually be on the verge of finding our magic weed control formula. All of you have heard in one way or another of those chemical substances in plants called hormones or growth-regulating substances which in infinitesimally small amounts regulate plant growth. One might be inclined to expect that if a "little" of such substances is good for plants, "more" would be better. Actually in this case "more" is disastrous, and instead of being stimulated to better growth the plant is killed. And the surprising thing is that "more" is still a very small quantity as we usually think of herbicides. And even more surprising

is the selectivity in herbicidal effect of the very limited number of the growth regulators so far tested. Some species are killed, others are not affected to any extent. Preliminary work with bindweed indicates this weed as quite susceptible. Likewise when the growth regulator is applied to turf, narrow-leaf plantain and dandelion are killed, and the grass is not injured. These results are at least suggestive of interesting possibilities.

I wish, however, to emphasize that the work on growth regulators as weed killers has not reached a stage ready for immediate widespread use. Many details remain to be worked out. There are many of the regulator compounds yet to be tried, some of which may be better than those now being tested, and also different in their selective action on different weeds. Yet the results so far obtained hold promise beyond anything so far known in the herbicidal field. The quantities required are small. There seem to be no residual effects on the soil. The selective properties open up possibilities for use on weeds in growing crops, pastures, meadows, lawns, road rights of way, airport runways, etc., that presently used herbicides do not possess. Of course, there may be difficulties we now do not see, but even so results so far obtained suggest the kind of herbicidal action and other attributes we have always dreamed about, and now may even hope ultimately to find in the infinite number of organic compounds available for trial.

Even though ultimately we may find an ideal herbicide, it is my own belief that our primary reliance in weed control should and probably must depend on preventing and controlling infestations through good farming. Timely and adequate tillage, weed-free seed, good rotation and crop sequence, quarantine against weed-contaminated, outside-produced feed and forage, must be our chief reliance. Other measures can be only supplementary to plug the holes that are missed.

In this connection I wish to mention one item in weed control which is most difficult of solution, yet which for that very reason should receive special attention. The increase in farm weed infestations in this country from feeding weed seed contaminated emergency feed grains brought in from Canada has been noted. That seems a rather striking example of the damage from such carelessness, yet it is not a drop in the bucket when compared with weed seed moved from place to place in this country in our own feed grains and hay. The devitalization of weed seeds removed in cleaning farm seeds before such screenings can be shipped in interstate commerce is provided for in the Federal Seed Act, but there is no protection against the interstate shipment of other weed seeds contained in feed grains or hay. Proposals have been made for drafting legislation to control interstate shipment of feeds so as to prevent this movement of weed seed from state to state, but the difficulties of devising what seemed to be adequate yet reasonably enforceable regulatory procedures blocked this highly desirable step. State weed control officials should give this problem careful study, and bend every effort to working out ways of doing this job on a feasible basis. Without control over this menace

there is a serious question whether any real weed control can be attainable.

In the beginning of this rather rambling jaunt through our big national weed patch, I noted the emphasis which all discussions have placed on the need for more information. Additional research to meet this need is badly needed. A relatively little money spent in research can save many times this amount in control operations and can insure that the job will be done more effectively.

The primary purpose of weed research is to provide workable and practical methods that can be used by the farmer and control agencies to control weeds. There must be complete coordination between research and action on farms or wherever weeds are to be controlled. Experience in controlling weeds shows the deficiencies in existing knowledge and methods, and the mending of these breaks in our armor should be the function of research. The research man should work closely with control officials and farmers to learn problems at first hand, and to see how methods devised from research operate in action. Control officials in turn should be in close touch with research in order to apply its findings as quickly and as effectively as possible, and also to suggest on the basis of experience what items need additional research attention. As I see the problem of integration, this should not be merely a matter of casual though friendly contact and suggestion, but rather one of definitely recognized mutual obligation based on good will and a single-minded determination to do the best possible job for the public whose servants we are. The discussions and recommendations of this meeting should serve most effectively to implement such integration.

I also believe that the research program should deal in basic principles, which can serve as a foundation to devise methods for meeting whatever situation may arise. All of us, I think, will agree that the accomplishments of the cooperative bindweed research program have been substantial. I believe that this has been possible because the program stuck to basic principles, and recognized that methods to be devised from these principles must be fitted into the usual operations of good farming. By sticking to this somewhat single-track program, we have learned a great deal about bindweed, and have been able to use this information in devising workable practices to control this vicious pest under at least some conditions. More, of course, needs to be done to cover all situations. We have also been able to develop some general principles of rather wide application to all similar weeds, to a degree at least that they can serve in organizing research on the other weeds so as to get results more quickly and surely. I believe we should follow the same general policy in all weed research.

And finally, I would again emphasize that the final criterion of effective weed control is the smoothness and efficiency with which it fits into usual farm operations as one part of good husbandry. We must remember that weed control, while extremely important, is only one feature of good farming. Improved productivity and erosion control also must be carried along with weed control as essential parts of the whole. On the other hand, we can comfort ourselves with the thought that in the main everything that contributes to better

farming also contributes in some degree to weed control. And as education and training are necessary to attain these ends, so also should they be an essential part of weed control operations. Fact finding, education, application, make up our collective job in defeating the weed menace.

EFFECT OF SEEDCOAT INJURIES DURING THRESHING ON EMERGENCE OF FLAX SEEDLINGS[1]

Dwight D. Forsyth and O. A. Vogel[2]

THE emergence of flax in field plantings has varied widely during the years that varietal trials have been conducted by the Washington Agricultural Experiment Station at Pullman. The difficulty in obtaining an initial stand sometimes has made it necessary to reseed at a later date in the spring. In 1941 there was a marked difference in seedling emergence among varieties. Moreover, seed produced at Pullman gave poorer emergence than seed supplied by the University of Minnesota for the uniform flax nursery.

As seed of several varieties was saved from the supply used in planting the nursery, it was possible to test it for germination in the seed laboratory. The results showed that the germination of seed produced at Pullman was uniformly high, averaging 95.5% for four samples, as compared to 83% for seven samples of seed supplied by the University of Minnesota, a contradiction of the results in the field.

Because of the discrepancy between the results in the field and in the seed laboratory, tests of the same seed were made in sterilized and unsterilized soil, yielding pre-emergence damping-off only in the latter case. The germination tests made in this way showed that the seedlings from the Pullman seed were attacked by soil-borne organisms, the most common being tentatively identified by the Department of Plant Pathology as *Fusarium oxysporum* Schlecht., (4)[3] which resulted in seed decay and pre-emergence damping-off of the seedlings. Work on flax at other localities in the United States (3, 5), Canada (2), and Germany (1) suggests that this emergence problem might be related to the amount of mechanical damage to the seed. The present study deals with the effect of seedcoat damage in flaxseed on germination, and emergence of seedlings from soil.

MATERIALS AND METHODS

The flaxseed used in the experimental plantings in the nursery and the seed laboratory was produced at Pullman, Wash. The emergence data in the nursery were obtained by counting the number of seedlings in six 18-inch strips taken at random along the 20 feet of the middle row of each three-row plot of each variety.

The soil used for tests in the seed laboratory was taken from the college farm. This soil has always caused the same diseased condition of the flax seedlings, regardless of its previous cropping history. The soil sample from Tekoa, Wash., was obtained from the flax nursery at that location. Soils from four other sources

[1]Cooperative investigation of the Seed Laboratory, Department of Agronomy, State College of Washington, Pullman, Wash., and the Division of Cereal Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture. Published as Scientific Paper No. 629, College of Agriculture and Experiment Station, State College of Washington. Received for publication February 9, 1945.

[2]Seed Analyst, Department of Agronomy, State College of Washington, and Associate Agronomist, Division of Cereal Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering, U. S. Dept. of Agriculture, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 393.

were obtained from collections made by the Soils Section of the Division of Agronomy of the Experiment Station at Battleground, Chehalis, and Everett in western Washington and Spokane in eastern Washington.

In the laboratory tests, enamelware pans (9×12×2 inches) were filled to within an inch of the top with friable soil. The flaxseed was placed on this seedbed and covered with an inch of moist soil, after which the pans were covered with sheets of waxed paper to maintain the soil moisture.

The type and amount of seedcoat injury was determined from 200 seeds of each sample with the aid of a 7× hand lens. Each seed was classified on the basis of one of these types of injury: 1, No visible injury; 2, small cracks extending not over half the width of the seed; 3, large cracks extending across the seed, or multiple small cracks; 4, open cracks[4] with a relatively large opening in the seedcoat; and 5, broken seeds in which a part of the seed is missing.

EXPERIMENTAL RESULTS

AMOUNT OF SEED INJURY FROM THRESHING

In 1942 hand-threshed and machine-threshed seeds of the 1941 crop of three flax varieties, Zenith, Bison, and Victory, were available. Seed from this source was planted in the nursery and in soil in the seed laboratory. The results are given in Table 1. In both the field and the laboratory tests, emergence from the hand-threshed seed greatly exceeded that from the machine-threshed seed.

In 1943, hand-threshed and machine-threshed seed of Redwing and Bison flax was planted in the field and in soil in the seed laboratory. The threshing machine was run at two different cylinder speeds. At medium speed approximately 10% of the bolls were left unthreshed in order to give low seed damage. At high speed the cylinder was rotated just fast enough to thresh out all the bolls.

There was a progressive decrease in emergence with an increase in severity of the threshing methods, as indicated in Table 1. This trend was evident in both the field and laboratory tests. In 1943, however, the emergence of machine-threshed seed in the field was higher than would be expected on the basis of the tests in the laboratory. This discrepancy probably was due to dissimilar conditions of soil moisture, soil temperature, and seedbed preparation.

APPEARANCE OF DISEASED FLAX SEEDLINGS

In the emergence tests in soil in the seed laboratory a considerable number of the seedlings which emerged were diseased. The diseased condition consisted of irregular reddish-brown lesions which occurred any place on the seedling, above or below the soil. As previously mentioned, the organism causing the trouble in the laboratory was shown to be a *Fusarium*, probably *F. oxysporum*. Preliminary tests by the Department of Plant Pathology indicated that this was likewise the major cause for the trouble in the field. The long period between seeding and emergence caused by low soil temperatures in the field resulted in a more complete pre-emergence killing of the

[4]The term "open cracks" refers to a mechanical cracking or shattering of the seedcoat and not to the injury described by Moore and Christensen (3) as "exposure of the embryo due to a natural tendency of seed of certain varieties to split at the germ end". Embryo exposure did not appear to be a factor in seed produced at Pullman, although Moore and Christensen report it as being more common than mechanical injury in lots of seed studied by them.

TABLE 1.—*Effect of threshing method on the seedling emergence of flax in the field and in laboratory soil tests during 1942 and 1943.*

Variety	Method of threshing*	Seedling emergence		
		Field		Laboratory
		Seedling count†	Per cent of hand threshed	Per cent
		1942		
Zenith	Hand	426	100	92.0
	Machine, high speed	158	37	14.0
Bison	Hand	373	100	77.5
	Machine, high speed	70	19	6.5
Victory	Hand	315	100	87.0
	Machine, high speed	150	48	9.5
		1943		
Redwing	Hand	483	100	98.7
	Machine, medium speed	431	90	40.5
	Machine, high speed	387	80	15.5
Bison	Hand	387	100	99.2
	Machine, medium speed	307	79	24.0
	Machine, high speed	236	61	8.2

*Cylinder of thresher was run at two different speeds. Medium speed left 10% of bolls unthreshed, high speed threshed out all the bolls.

†Figures are average of two plots in 1942 and of one plot in 1943. Each figure represents the number of seedlings in 9 feet of the middle row of a three-row plot.

infected seedlings than was the case in the laboratory tests. Consequently, the appearance of diseased seedlings in the field was not common.

EFFECT OF DEGREE OF INJURY ON EMERGENCE

Microscopic inspection of flaxseed threshed by the nursery thresher at Pullman revealed a considerable amount of damage to the seedcoat. This damage consisted of small cracks, bruises, and crushed areas that were so slight that magnification with a 7× hand lens was necessary to see the injury. The data obtained by separating samples of flaxseed according to the five types of seedcoat injury and making emergence tests on each type in soil are given in Table 2.

Almost complete failure of emergence occurred in types 4 and 5, representing open cracks and broken seed, respectively. Some reduction in emergence from seed of these types could be expected in soil from any source, since the seed gave a high percentage of abnormal seedlings in standard germination tests on blotters. Type 3, representing large or multiple cracks, showed practically complete failure of emergence. In tests on blotters this seed germinated normally for the most part. Type 2, or seed with small cracks, showed considerable failure of emergence as compared with the emergence obtained

TABLE 2.—*Types and amounts of seed injury in different lots of flax threshed at Pullman, Wash., in 1942, emergence from seed of each type and total for all types, and germination of each lot on blotters.*

Variety	Method of threshing*	Type of seed injury and percentage emergence†					Total emergence from all types, %‡	Germination on blotters, %
		1, no cracks	2, small cracks	3, large cracks	4, open cracks	5, broken seeds		
A.P.B.	Machine, medium	30.0 (65.0)	56.5 (18.6)	7.5 (6.6)	6.0 (8.3)	0.0 (0.0)	31.0	98.5
Royal	Machine, medium	34.0 (47.0)	37.0 (13.5)	10.0 (5.0)	16.0 (0.0)	3.0 (0.0)	21.5	90.5
Viking	Machine, medium	40.0 (52.5)	42.0 (9.5)	8.0 (0.0)	8.0 (0.0)	2.0 (0.0)	25.0	90.5
Rio	Machine, medium	35.0 (72.9)	48.0 (14.6)	6.0 (0.0)	9.0 (0.0)	2.0 (0.0)	32.5	97.0
Redwing	Hand	100.0 (100.0)	— —	— —	— —	— —	100.0	98.0
Redwing	Machine, medium	39.5 (82.3)	54.5 (46.8)	3.0 (66.6)	2.5 (20.0)	0.5 (0.0)	60.5	99.5
Redwing	Machine, high	17.5 (68.6)	53.5 (22.4)	18.5 (0.0)	7.5 (0.0)	3.0 (0.0)	24.0	97.5
Bison	Hand	100.0 (99.5)	— —	— —	— —	— —	99.5	99.5
Bison	Machine, medium	28.0 (66.1)	53.0 (21.7)	13.0 (0.0)	5.5 (0.0)	0.5 (0.0)	30.0	97.5
Bison	Machine, high	12.5 68.0	46.0 9.8	24.0 0.0	10.5 0.0	7.0 0.0	13.0	89.0

*Cylinder of thresher was run at two different speeds. Medium speed left 10% of bolls unthreshed, high speed threshed out all the bolls.
†Figures without parenthesis are percentages of seeds in each type; the figures in parenthesis are percentage emergence of seed in each type.
‡Total emergence from all types is the sum of the actual emergence in the five types.

from undamaged seed in type 1. From these tests it is evident that even slight injuries affect the emergence of flax planted in Pullman soil.

The tests with seed threshed by hand and at different cylinder speeds show that machine threshing is the source of the mechanical injury to the seed. Apparently, machine threshing produced injuries which were not visible even under magnification as shown by the difference between the emergence from seed having no cracks selected from machine-threshed samples and the emergence from hand-threshed seed. These minor injuries were not detectable in standard germination tests.

EFFECT OF SOIL SOURCE ON EMERGENCE

Samples of Redwing and Bison seed which had been threshed both by machine and by hand were planted in pans containing soil obtained from six different localities in Washington. The emergence data are given in Table 3.

The hand-threshed seed gave practically perfect emergence in all cases, except for Bison planted in the Spokane soil in which the germi-

TABLE 3.—*Seedling emergence from machine- and hand-threshed seed of Bison and Redwing flax planted in soils from six different sources in Washington.*

Soil source	Percentage seedling emergence			
	Bison		Redwing	
	Hand-threshed	Machine-threshed	Hand-threshed	Machine-threshed
Pullman	100	62	100	70
Battleground	99	94	100	96
Chehalis	100	87	100	95
Everett	98	76	100	80
Spokane	88	81	99	94
Tekoa	97	91	100	98

nation of the seed was lowered owing to decay of the seed. The machine-threshed seed, on the other hand, gave a wide variation in the emergence from the different soils, all the way from no appreciable reduction in stand for Redwing grown in the Tekoa soil to a 38% reduction in the case of Bison grown in Pullman soil. In no case did the characteristic reddish-brown lesions of the diseased seedlings growing in the Pullman soil appear on the plants in the five other soils. The decrease in stand in the Everett soil was almost as great as that in the Pullman soil, but the decrease was due to weak seedlings which was not the case in any of the other soils. Organisms which caused seed decay and pre-emergence damping-off appear to be present in all of these soils to a certain extent, although not to the same extent that they occur in Pullman soil used in these tests.

DISCUSSION

Previous work on the effect of seed damage to flax has been concerned, for the most part, with badly cracked and broken seeds. Such easily observed damage to the Pullman seed was not as great as the damage reported from other localities. Stevens (5) reported figures for the purity analyses of flaxseed from the North Dakota Seed Laboratory for the crop years of 1931 and 1932 in which all samples examined contained an average of 4.5% by weight of pieces that were less than half seeds. In a separation of flaxseed, reported in the same paper, it was found that 8.4% of the seed from 11 samples of Bison had parts of the seed broken off. This condition could be considered similar to type 5 as used in the present work. Moore and Christensen (3) found a range of 0 to 32% of mechanical cracking and shattering of the seedcoat in seed lots of Bolley Golden selection C. I. 976 grown in 31 localities in the United States and Canada.

Machacek and Brown (2) reported that, on an average, half the seed in samples of flaxseed examined from western Canada during 1940 failed to germinate. Since the amount of broken seed reported was much higher than that found in the Pullman seed, it can be assumed that the microscopic injuries likewise were higher.

In the present work it was found that the small microscopic cracks and bruises in the seedcoat had a marked effect on emergence of flax at Pullman, Wash. This conclusion concerning the importance of microscopic damage is similar to that arrived at by Tatum and Zuber (6), working with seed corn in Iowa. They found that minor pericarp injuries over the embryo are important in reducing the stand obtained in the field. These workers found that germinating seed corn in nonsterile soil by their "cold test" method gave results which closely approximated the results obtained in the field, whereas the standard laboratory germination did not.

Seed testing is concerned with obtaining the maximum germination on each lot of seed as the best criterion of the results to be obtained in the field. Soil has not been favored as a substratum by seed analysts because it does not give as uniform results and is not as easy to handle as other types, such as blotters, paper toweling, or sand. However, it has been found at Pullman that the germination test for flax by standard laboratory procedure on blotters does not indicate the ability of different lots of seed to produce stands in the field. This discrepancy has been shown to be the result of a combination of two factors, namely, seedcoat injury and the presence of infectious soil-borne organisms. It appears that the best practical method for evaluating seed lots for growing under Pullman conditions is to run tests in nonsterile soil in conjunction with the standard germination test.

No appreciable reduction in yield was caused by the reduced emergence of flax in the Pullman nursery unless the stand was patchy or very thin. Such a lack of reduction in yield held true because of the branching habit of the flax plant, which compensated for rather large variations in stand, and because of the lack of weed competition in the nursery. However, where early spring weeds compete with the flax seedlings, as is the case in a farmer's field, the initial emergence would become a factor of prime importance in establishing a satisfactory stand.

Seed treatment with a number of commercial compounds has been shown to give satisfactory control of the seed decay and pre-emergence damping-off organisms in reports of tests at Pullman, Wash., (4), in Minnesota (3), and in Canada (2).

SUMMARY

1. Two important causes of the yearly variation in initial stands of flax obtained at Pullman, Wash., are shown to be considerable amounts of minor mechanical damage to the seed, and the presence of soil-borne organisms, mainly *Fusarium oxysporum*.

2. Machine threshing was the main source of the mechanical damage to the seed.

3. The problem of poor emergence is not as acute in soils from other areas on which tests were performed as it is in soil from Pullman. This is apparently due to differences in soil microflora.

LITERATURE CITED

1. HÄRTEL, KURT. Über druschverletzten Lein und keimverletztes Getreide und ihre Beurteilung bei der Reinheitsbestimmung. Proc. Int. Seed Test. Assoc., 8:213–223. 1936.
2. MACHACEK, J. E., and BROWN, A. M. Preliminary Investigations on mechanical injury in flax seed. Phytopath., 32:733–734. 1942.
3. MOORE, M. B., and CHRISTENSEN, J. J. Natural and mechanical injury in flax in relation to seed treatment. Phytopath., 33:1117. 1943.
4. SCHUSTER, MAX L., FORSYTH, DWIGHT D., and HARRAR, J. G. Influence of certain diseases and threshing injury on flax stands in Washington. Wash. Agr. Exp. Sta. V Circ. 8. 1943.
5. STEVENS, O. A. Germination studies on aged and injured seeds. Jour. Agr. Res., 51:1093–1106. 1935.
6. TATUM, L. A., and ZUBER, M. S. Germination of maize under adverse conditions. Jour. Amer. Soc. Agron., 35:48–59. 1943.

THE YIELD AND SUGAR CONTENT OF ALFALFA CUT AT VARIOUS TIMES OF DAY AND THE SUGAR CONTENT OF THE HAY AFTER VARIOUS METHODS OF DRYING[1]

S. T. DEXTER[2]

CURTIS (1)[3] recently reported that cuttings of alfalfa made in the afternoon contained approximately 19% more dry matter and 83% more sugar on an acre basis than if cut the morning before or the morning after. That the content of sugars in plants varies considerably from day to day or from hour to hour has been well recognized. Thus, Wilson and Webb (6) reported findings which indicated that the sugars in alfalfa on July 1, 1935, were highest at 4:40 a.m. and 6.40 a.m. Swedish workers (4) agreed with Curtis that hays were frequently somewhat higher in sugars in the afternoon than in the morning, but that the content of sugars was influenced considerably by cloudy or rainy weather.

That the total dry matter in almost mature stems of alfalfa usually decreases 19% overnight, or increases 19% during any one day, seems somewhat improbable in view of the results of extensive studies of the field weights of alfalfa. In making the ordinary routine harvests of large blocks of alfalfa plots, suitably replicated, when harvest has continued all of one day and part of the next, no such diurnal changes in yield have been observed.

In 1944, however, in order to examine these important claims more thoroughly, parallel routine harvests were made, night and morning, on certain plots. For a 3-day period in addition, harvests were made three times a day on a large area devoted exclusively to this study. These fields yielded approximately 5,000 pounds of dry matter per acre, and were excellent stands of pure alfalfa. Samples were taken for drying in four ways, namely (a) prompt drying for chemical analysis in a blast of air heated to about 65° C; (b) slower drying about 3 days of 50-pound samples in circulated unheated air; (c) still slower drying (about 3 weeks) in a mow-drier of about 15 tons of hay; and (d) field drying. From these lots of hay, samples were taken for chemical analysis to determine the original content of sugars and starch and their retention during the drying process.

During the entire period of the experiment, the weather remained clear and warm with few clouds. Data from the local U. S. Weather Station show that on each day, the wind velocity was approximately 15 miles per hour, the relative humidity from 40 to 60, and there was little if any dew. On June 28, the "possible sunshine" was 98%; on June 29, 92%; and on June 30, 94%. Maximum-minimum temperatures for the three days were: June 28, 94° and 72°; June 29, 78° and 60°; June 30, 73° and 49°. Heavy rains the previous week had supplied abundant moisture for growth. Curtis (2) states in comment on notes by Woodward, *et al.*, and Willard (5, 7) that his "average

[1]Contribution from Section of Farm Crops, Michigan Agricultural Experiment Station, East Lansing, Mich. Journal Art. 748 (New Series). Received for publication February 13, 1945.

[2]Research Associate in Farm Crops.

[3]Figures in parenthesis refer to "Literature Cited", p. 399.

was based on figures obtained on days that had few or no clouds" and that "an attempt was made to select days that would give maximum gains." Except that his selected days were not consecutive, nor at the height of haying season, and admittedly do not represent an average, but rather a "maximum", our experimental conditions are rather closely comparable.

On June 26, at 5 p.m., four 6-foot mower swaths were cut, in pairs of two, across a series of 13 plots, each 14 feet wide. The next morning, two similar swaths were taken, between the first two pairs. The green weight and the percentage moisture were determined. The yield of dry matter was computed and the figures are presented in Table 1.

TABLE 1.—*Dry matter yields per plot (168 sq. ft.) of alfalfa cut in the evening compared with alfalfa cut the next morning.*

Plot No.	South plots, evening cut, lbs.	Center plots, morning cut, lbs.	North plots, evening cut, lbs.
1	18.4	16.9	17.2
2	14.4	16.1	17.3
3	16.4	16.9	17.6
4	16.1	17.6	18.6
5	14.1	15.8	14.3
6	15.9	14.2	17.6
7	16.8	16.0	16.9
8	15.9	14.9	15.9
9	14.5	14.5	10.4
10	15.0	15.2	15.1
11	15.6	12.7	11.9
12	14.2	13.7	15.4
13	16.0	16.2	12.6
Total............	203.3	200.7	200.8

It will be observed that the total weights of the 13 plots differ by a little more than 1%. The gain or loss in weight overnight appears to have been slight.

On June 28, 29, and 30, one swath 177 feet long and 30 inches wide (1/102 acre) was cut in the morning, one at noon, and one toward evening. A tractor-driven mower was used. According to "solar time", 8–9 a.m., 12–1 noon, and 4–4:30 p.m. would include the three times of cutting. The hay was never wet with dew when cut in the morning. Green weights were determined and samples weighing about 2 kilograms each were taken for the determination of percentage dry matter. On June 28, morning, noon, and evening, samples of green hay weighing 50 pounds each were put in a "corn drier", where they were dried with circulated, unheated air in a period of about 3 days. On June 29, three swaths were cut and weighed at noon to determine the probable variation in weight between swaths. A final swath was cut on the morning of the fourth day, July 1. Table 2 gives the weights obtained. Table 3 summarizes these data.

The arrangement of the swaths in the field was as follows: June 28, evening; June 28, morning; June 28, noon; June 29, morning; June 29,

TABLE 2.—*Yield of alfalfa hay cut in the morning, at noon, and in the late afternoon.*

Date	Green weight, lbs.	Percentage dry matter	Dry weight, lbs.
June 28:			
8 a.m.	167.4	27.9	46.8
12 noon	178.7	27.9	49.9
4 p.m	165.0	26.9	44.4
June 29:			
8 a.m	186.0	27.2	50.6
12 noon	163.0 170.8 186.0	28.3 28.3 28.3	46.1 48.3 52.6
Average:			
12 noon	173.3	—	49.0
4 p.m	187.0	27.4	51.2
June 30:			
8 a.m	189.2	26.6	50.4
12 noon	181.1	28.4	51.4
4 p.m	176.3	27.8	49.0
July 1:			
8 a.m.	198.0	28.5	56.4

TABLE 3.—*Average yields, from Table 2, of alfalfa hay cut at various times of day.*

Time	Dry weight yield per plot, lbs.	Dry weight yield per acre, lbs.
Morning cuts:		
All 4 weights	51.0	—
First 3 weights	49.2	—
Noon cuts:		
All weights	50.1	—
First 3 weights	49.2	—
Evening cuts:		
First 3 weights	48.2	—
June 28, av. all weights	—	4,796
June 29, av. all weights	—	5,029
June 30, av. all weights	—	5,128

noon (1); June 29, noon (2); June 29, noon (3); June 30, morning; June 29, evening; June 30, noon; June 30, evening; July 1, morning.

From the figures in Table 2, there is no indication that great losses in weight occurred overnight. The average increase of 100 to 200 pounds of dry matter per acre per day is strictly in accord with many other published and unpublished data.

The uncured samples taken for chemical analysis were dried rapidly in a blast of air at 65° to 70° C. Analysis for sugars and starches was performed by the Michigan State College Agricultural Chemistry Department. The results of these analyses are shown in Table 4.

With a considerable degree of uniformity, we find that the percentage of sugars and starches built up somewhat in the stems and leaves during the day. It is quite possible that the discrepancies

TABLE 4.—*Percentage of sugars and of starch in alfalfa hay cut at various times of day.*

Date	Dried rapidly, circulated air 70°C				Dried in 3 days in "corn drier" without heat			
	Starch	Total sugars	Sum	Av.	Starch	Total sugars	Sum	Av.
June 28:								
Morning cut	1.20	3.26	3.46		0.86	2.03	2.89	
Noon cut	1.32	3.73	5.05	5.19	0.86	2.41	3.27	3.63
Evening cut	1.67	4.38	6.05		0.83	3.89	4.72	
June 29:								
Morning cut	1.09	3.30	4.39		—	—	—	—
Noon cut	1.14	3.16	4.30	4.44	—	—	—	—
Evening cut	1.32	3.31	4.63		—	—	—	—
June 30:								
Morning cut	1.08	3.13	4.21		—	—	—	—
Noon cut	1.21	3.31	4.52	4.55	—	—	—	—
Evening cut	1.08	3.83	4.91		—	—	—	—
July 1:								
Morning cut	1.24	3.31	4.55		—	—	—	—
Average of 3 days								
Morning	—	—	—	4.40	—	—	—	—
Noon	—	—	—	4.62	—	—	—	—
Evening	—	—	—	5.20	—	—	—	

that do occur might have been due to brief periods of cloudiness at some time previous to cutting. On June 28, the hottest and clearest day, the content of sugar and starch was the highest of the 3 days.

In the samples that were dried over a period of 3 days, the relatively higher level of sugars was maintained in the samples cut in the evening, although the losses were considerable in each case.

On June 14, starting about 1:30 p.m., an 8-acre field of mixed alfalfa and smooth brome grass was cut. Somewhat more than half of the field was cut before 5 p.m. and the rest before 11 a.m. of the next day. Starting at 2 p.m. on Thursday, June 15, this hay was put in a "ventilated mow drier". No rain fell on any of this hay after it was cut. In general, the hay was hauled progressively from one edge of the field. Thus, the first hay put in the mow was cut about 2 p.m. June 14, as was also the last hay put in. This last hay had a moisture content of 31%, being almost completely cured in the field, and completed drying at the edges of the mow in a day or two. Hay in the middle of the mow, vertically, was cut late in the afternoon and the next morning. About 15 cubic feet of air per minute per square foot of floor space was blown through the hay. The hay put in first, and through which the incoming air first passed, dried relatively rapidly. That in the middle or near the top required 3 weeks before drying was completed. In September, a trench was cut through the hay from top to bottom (about 10 feet in settled depth). Ten samples were taken, at intervals of about a foot, and were analyzed for sugars as before. Table 5 shows the results of these analyses.

TABLE 5.—*The content of sugars and starch in hays dried rapidly and slowly.*

Position of sample in mow, from bottom	Estimated time of		Moisture % as put in	Sugar, %	Starch, %	Sum
	Cutting	Putting in mow				
1 foot..........	2 p.m. Wed.	Thurs. p.m.	50	2.69	0.68	3.37
2 feet..........	3 p.m. Wed.	Thurs. p.m.	45	2.08	0.87	2.95
3 feet..........	11 a.m. Thurs.	Fri. a.m.	45	1.26	0.54	1.80
4 feet..........	4 p.m. Wed.	Fri. a.m.	40	2.63	0.51	3.14
5 feet..........	10 a.m. Thurs.	Fri. p.m.	38	1.03	0.68	1.71
6 feet..........	10 a.m. Thurs.	Fri. p.m.	38	0.54	0.54	1.08
7 feet..........	11 a.m. Thurs.	Fri p.m..	38	1.32	0.89	2.21
8 feet (slight mold)	4 p.m. Wed.	Fri. p.m.	35	0.70	0.52	1.22
9 feet (slight mold)	3 p.m. Wed.	Sat. a.m.	35	2.50	0.62	3.12
10 feet (edges of mow)..........	2 p.m. Wed.	Sat. a.m.	31	4.10	0.51	4.61

Hay cut in the afternoon and dried fairly quickly, either in the field or in the mow, had a much higher content of sugar and starch than hay cut either morning or afternoon that dried slowly. Although the samples cannot be identified positively as to the hour at which they were cut, the effect of slow drying is unmistakable. This hay is being used in feeding trials in an attempt to determine its feeding value with dairy cattle.

SUMMARY AND DISCUSSION

In an experiment designed to measure the yield of alfalfa hay when cut at various times of day, it was found that no marked increases occurred from morning until night, nor were large decreases found from evening until the next morning. At about one-half bloom, a growth of about 100 to 200 pounds dry matter per acre per day was found. The average fluctuation in yield of 19% between night and morning reported by Curtis was in no way approximated.

In almost continuously sunny weather, there was a small but rather consistent increase in the percentage of sugars and starch in the hay as the day proceeded. The highest percentage of these carbohydrates was found on the brightest and hottest day.

When samples of hay were dried in unheated circulated air, over a period of 3 days, there was a considerable loss of sugars as compared with rapidly dried samples. Whether this sugar was lost as carbon dioxide in respiration, or used in the synthesis of other materials, is not known. Certain data from Henson (3) suggest the former. When hay was dried much more slowly over a period of about 3 weeks in a "mow drier", the losses of sugar were still more pronounced. Ordinary field-cured hay was far higher in sugars than the hay dried slowly in the mow. Precisely how much difference in actual feeding value will result from such differences in sugar content remains to be determined. The feeding trials now in progress may give some idea of the influence of slow mow drying, in deep mows, upon the feeding value of the hay.

LITERATURE CITED

1. CURTIS, O. F. The food content of forage crops as influenced by the time of day at which they are cut. Jour. Amer. Soc. Agron., 36:401–416. 1944.
2. ———. Afternoon vs. morning cutting of alfalfa: Comments on notes by Woodward, Shepherd and Tysdal, and by Willard. Jour. Amer. Soc. Agron., 36:943–952. 1944.
3. HENSON, E. R. Curing and storage of alfalfa hay. Iowa Agr. Exp. Sta. Res. Bul. 251. 1939.
4. SVANBERG, O., and EKELUND, S. The sugar content of hay and factors affecting it. (Translated title.) Herb. Abst., 14:41. (Abst. 198). 1944.
5. WILLARD, C. J. Afternoon vs. morning cutting of alfalfa. Jour. Amer. Soc. Agron., 36:937–939. 1944.
6. WILSON, J. K., and WEBB, H. J. Water-soluble carbohydrates in forage crops and their relation to the production of silage. Jour. Dairy Sci., 20:247–263. 1937.
7. WOODWARD, T. E., SHEPHERD, J. B., and TYSDAL, H. M. Yield and chemical content of alfalfa cut at different times of day and night. Jour. Amer. Soc. Agron., 36:940–943. 1944.

NOTES

A HULLER FOR CLOVER HEADS

IN 1943 and 1944 the author was confronted with the problem of removing the seed from approximately 4,000 bags of clover heads. The number of clover heads per bag varied from 150 to 600. To hull this volume of clover heads by hand methods would have involved hundreds of hours of labor and great expense. With this problem at hand the author, because of necessity, began to assemble plans for a mechanical clover huller that would operate with speed and efficiency. The planning provided for the combining of the fundamental principles that are commonly built into the commercial clover hullers, the hammer mill, and those of the various hand methods that may be used to hull clover seed. The final product of the author's thoughts and efforts are herein presented for review by those who may be interested in a small mechanical clover huller. This huller has speed, accuracy, and efficiency. The accuracy of the machine is practically 100% because the clover seed cannot leave the hulling compartment until the hull is removed from the seed.

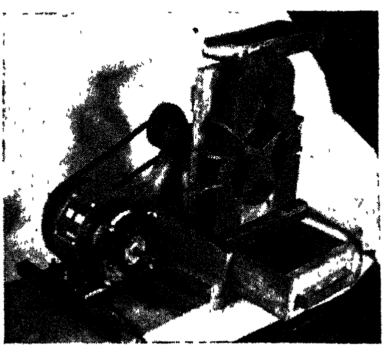

FIG. 1.—A huller for clover heads.

Figs. 1 and 2 show the general construction plan of the huller. The stationary and revolving beaters are made of rubber cut from the sidewalls of a four-ply automobile tire. Except for the beater shaft, belt pulley, and screen, the entire machine is made of wood, rubber, and glass. Seasoned walnut was used for the beater and the wooden housing that surrounds the beater. Seasoned poplar was used for the wooden bearings that were equipped with wick-type oilers. The general frame construction is from seasoned white pine. All joints were closed and held in place by both wood screws and glue.

The multiple speed V-belt pulley allows for adjustment of the beater speed from 800 to 1,800 R.P.M. A speed of 1,200 R.P.M. was found to be very satisfactory for dry clover heads. Both the stationary and the rotating rubber beaters can be adjusted quickly and easily. The stationary beaters are held firmly by wooden wedges made from seasoned walnut. The rotating beaters are held in position by screws. To keep down vibration the rotating beaters must be of equal weight.

The adjustment of the beaters was found to be much less frequent than expected for 200,000 heads were hulled before the first adjustment for wear was necessary, The machine was powered by a 1/3 H.P. electric motor equipped with a built-in switch for starting and stop-

FIG. 2.—Details of construction of the clover huller.

ping. The actual power needed to operate this huller is very low and probably not more than 1/6 H.P.

The screen through which the clover seed passes as it leaves the hulling compartment was made of 16-mesh per inch copper window screen soldered to a sheet metal frame. The entire front of the huller compartment is covered by a piece of shatter proof plate glass held firmly in place by two strong rubber bands cut from automobile tire tubes. The plate glass was removed when photographs were taken. The glass cover provides complete view of the hulling process at all times and the operator can quickly determine if all of the clover seed has been discharged from the hulling compartment. To keep down dust, the entire machine is vacumized by connecting the huller to an air suction line. A sliding valve is used to control the flow of air through the huller. With proper vacuum there is no escape of dust. This is a very important item because dust from clover heads can be very annoying to the operator if he should be susceptible to hay fever.

Baffle blocks are essential to keep the hulled seed from bouncing up and out of the hulling compartment. (See photographs.)

The huller was used to hull hundreds of single head samples and the author believes the machine is much more accurate than any hand hulling system because no seed is lost from the huller and the item of "personal reliability" is minimized because once the clover head goes into the huller it cannot get out until every clover seed is hulled. The clover head is pulverized until it is fine enough to pass through the screen with the clover seed.

The clover seed was separated from the clover head chaff by pouring the entire mixture slowly into the "Bates Laboratory Aspirator" which is commonly used for cleaning grain samples. This aspirator proved to be a very satisfactory piece of equipment for cleaning the clover seed. A 500-head collection of medium red clover heads can be put through both the huller and the Bates aspirator in about 3 minutes.

This huller was also used to hull ladino clover and alfalfa. By using larger screens and making a few minor adjustments it could also be used to hull head samples of wheat and barley.—HOWARD WM. HIGBEE, *Department of Agronomy, Pennsylvania State College, State College, Pa.*

POLYPLOIDY IN SUGAR BEETS INDUCED BY STORAGE OF TREATED SEED

THE induction of polyploidy in sugar beets by the application of a seed treating dust containing 5% ethyl mercury phosphate to the seed and to the soil was reported by Lynes and Harris in 1942.[1] This work suggested the possible induction of polyploidy through storage of sugar beet seed treated with small amounts of this material. The commercial acceptance of sheared seed in 1942 revived the interest in seed treatments and subsequent storage problems. Storage tests were begun at this time at all Holly Sugar Corporation factories to determine the keeping qualities of sugar beet seed under the respective warehouse conditions. Untreated seed and seed treated with Improved Ceresan for both sheared and whole beet seed were used. The author recently obtained samples of these stored bags to determine the presence and extent of induced polyploidy.[2] Table 1 shows the results obtained from the stored treated samples. Samples of stored bags of untreated seed for all conditions shown in Table 1 were also examined and no indication of polyploidy was observed.

The number of polyploids induced per 100 sprouts was determined by examination of the sprouts produced by duplicate samples of 100 seed balls each on paper toweling in a Minnesota germinator. Thickened radicles and hypocotyls were used as evidence of induced polyploidy.[3] Studies of the survival of the induced polyploids were made by planting seed in greenhouse soil to a depth of ¾ inch. Many of the induced polyploids did not emerge from the soil. Death losses and reversion to diploids accounted for the majority of the polyploids which did emerge. The data show the relatively small number of polyploids surviving at the end of 21 days.

A number of comparisons may be made from the data in Table 1.

[1]LYNES, F. F., and HARRIS, C. D. Polyploidy in sugar beets induced by the use of colchicine, ethyl mercury phosphate, and other chemicals. Amer. Soc. Sugar Beet Tech. Proc., 1942: 304–309. 1942.

[2]Credit is due C. E. Cormany, Chief Agronomist, Holly Sugar Corporation, for supplying the samples of seed from the storage tests.

[3]ARTSCHWAGER, ERNST. Indications of polyploidy in sugar beet induced by colchicine. Amer. Soc. Sugar Beet Tech. Proc., 1940:120–121. 1940.

————. Colchicine-induced tetraploidy in sugar beets: Morphological effects shown in progenies of a number of selections. Amer. Soc. Sugar Beet Tech. Proc., 1942:296–303. 1942.

TABLE 1.—*Polyploidy resulting from storage of treated sugar beet seed.*

Variety	Location	Type of warehouse	Type of bag	Type of seed	Dust treatment	Storage time, years	No. of obvious polyploids per 100 sprouts	No. of obvious polyploids, per 100 sprouts alive after 21 days
Midwest 4C	Sidney, Mont.	Corr. iron	Burlap	Sheared	Cer. and F.P.*	2	15.17	1.22
Midwest 4C	Sidney, Mont.	Corr. iron	Burlap	Whole	Cer. and F.P.*	2	11.59	0.29
Midwest 4C	Torrington, Wyo.	Tile	Burlap	Sheared	Cer. and F.P.*	2	5.71	0.34
Midwest 4C	Torrington, Wyo.	Tile	Burlap	Whole	Cer. and F.P.*	2	1.13	0.00
Midwest 4C	Torrington, Wyo.	Tile	Cotton	Sheared	Cer. and F.P.*	1	17.30	0.66
Midwest 4C	Swink, Colo.	Corr. iron	Burlap	Sheared	Cer. and F.P.*	2	66.66	11.00
Midwest 4C	Swink, Colo.	Corr. iron	Burlap	Whole	Cer. and F.P.*	2	69.02	13.13
Midwest 1	Swink, Colo.	Corr. iron	Paper	Sheared	Cer. and F.P.*	1	2.94	0.00
Midwest 3	Sheridan, Wyo.	Corr. iron	Burlap	Sheared	Cer. and F.P.*	2	8.47	0.47
Midwest 3	Sheridan, Wyo.	Corr. iron	Burlap	Whole	Cer. and F.P.*	2	3.37	0.00
US 22	Delta, Colo.	Corr. iron	Burlap	Sheared	Cer. and F.P.*	2	8.88	2.39
US 22	Delta, Colo.	Corr. iron	Burlap	Whole	Cer. and F.P.*	2	4.00	0.29
US 22	Grand Junction, Colo.	Brick	Burlap	Sheared	Cer. and F.P.*	2	6.52	0.00
US 22	Grand Junction, Colo.	Brick	Burlap	Whole	Cer. and F.P.*	2	9.09	0.00
US 22	Worland, Wyo.	Corr. iron	Cotton	Sheared	Cer. and F.P.*	1	0.00	0.00
US 22	Stockton, Calif.	Corr. iron	Burlap	Sheared	Cer. and F.P.*	2	28.07	5.36
US 22	Stockton, Calif.	Corr. iron	Burlap	Whole	Cer. and F.P.*	2	14.96	0.64
US 22	Stockton, Calif.	Corr. iron	Paper	Sheared	Cer. and F.P.*	2	12.24	0.00
US 22	Stockton, Calif.	Corr. iron	Paper	Whole	Cer. and F.P.*	2	11.38	0.72
US 22	Stockton, Calif.	Corr. iron	Burlap	Sheared	Ceresan†	2	48.93	19.58
US 22	Stockton, Calif.	Corr. iron	Burlap	Whole	Ceresan†	2	13.19	1.16
US 22	Stockton, Calif.	Corr. iron	Paper	Sheared	Ceresan†	2	21.56	0.00
US 22	Stockton, Calif.	Corr. iron	Paper	Whole	Ceresan†	2	8.39	0.32
Average for Stockton			All burlap			2	26.29	6.68
Average for Stockton			All paper			2	13.39	0.26
Average of all locations			All types	Sheared		2	22.22	4.04
Average of all locations			All types	Whole		2	14.61	1.66

*Mixture of 4 oz. Improved Ceresan and 8 oz. fume phosphate per 100 lbs. seed.
†4 oz. Improved Ceresan per 100 lbs. seed.

The data from the material stored at Stockton show that the amount of induced polyploidy for sheared seed is greater when Improved Ceresan is used alone than when used in combination with fume phosphate. The Stockton data also show that approximately twice as many polyploids were induced when the seed was stored in burlap bags as when stored in paper bags. The variations obtained at different locations indicate the importance of environmental conditions. With two exceptions, a larger number of polyploids were induced in sheared seed than in whole seed. The averages for all locations of the 2-year storage samples show almost twice as many induced polyploids in sheared seed as in whole seed.

The 1 year storage material shows variations from 0 to 17.30% induced polyploidy, and the 2-year storage material shows variations from 1.13 to 69.02%. The number of obvious polyploids surviving in soil after 21 days is not large and therefore the occurrence of these polyploids in a commercial beet field would not be of importance. However, under storage conditions where large numbers of polyploids are induced, the loss of stand due to the death of the polyploids would be important. The fact that polyploidy may be induced in sugar beets as a result of storage of seed treated with Improved Ceresan is important in the case of seed used for breeding work or for seed production purposes.—FRANK F. LYNES, *Beet Seed Breeding Department, Holly Sugar Corp., Sheridan, Wyo.*

RAPID DETERMINATION OF POTASSIUM AND MAGNESIUM CONTENT OF APPLE LEAVES

ANALYSES of leaves for potassium and magnesium have been found useful in the estimation of the needs of apple trees for fertilizers containing those nutrients.[1] The data presented here indicate that the semi-quantitative methods for soil analysis described by Peech and English[2] are accurate enough for this diagnostic work and may be substituted for the more quantitative procedures.

Sixty composite leaf samples taken in July, 1943, from seven commercial McIntosh apple orchards were used in this study. These samples were analyzed for potassium and magnesium by the quantitative micromethods of Peech[3] and by the rapid microchemical tests described by Peech and English.[4]

In the preparation of the extracts for the rapid chemical tests, the following procedure was followed: One gram of dried leaf material was mixed with 50 ml of the extracting solution (sodium acetate buffer at pH 4.8), and allowed to stand for 12 hours. Upon addition of 50 cc more of the extracting solution, the mixture was transferred quantitatively to a Waring blendor cup, and blended for 3 minutes. One half teaspoonful of activated carbon (Darco G 60) was then added

[1]BOYNTON, D., and COMPTON, O. C. Leaf analysis in estimating the potassium magnesium and nitrogen needs of fruit trees. Soil Sci., 59:———. 1945.

[2]PEECH, M., and ENGLISH, L. Rapid microchemical soil tests. Soil Sci., 57: 167–195. 1944.

[3]PEECH, M. Determination of exchangeable basis in soils. Rapid micromethods. Ind. & Eng. Chem., Anal. Ed., 13:436–441. 1941.

[4]*Loc. cit.*

and the stirring resumed for 1 minute. The liquid was then filtered through a Whatman No. 32 filter paper. The rapid chemical tests were made on separate aliquots of the extract, using the turbidimetric cobaltinitrite test for potassium and the colorimetric *p*-nitrobenzeneazoresorcinol test for magnesium as described by Peech and English.[5]

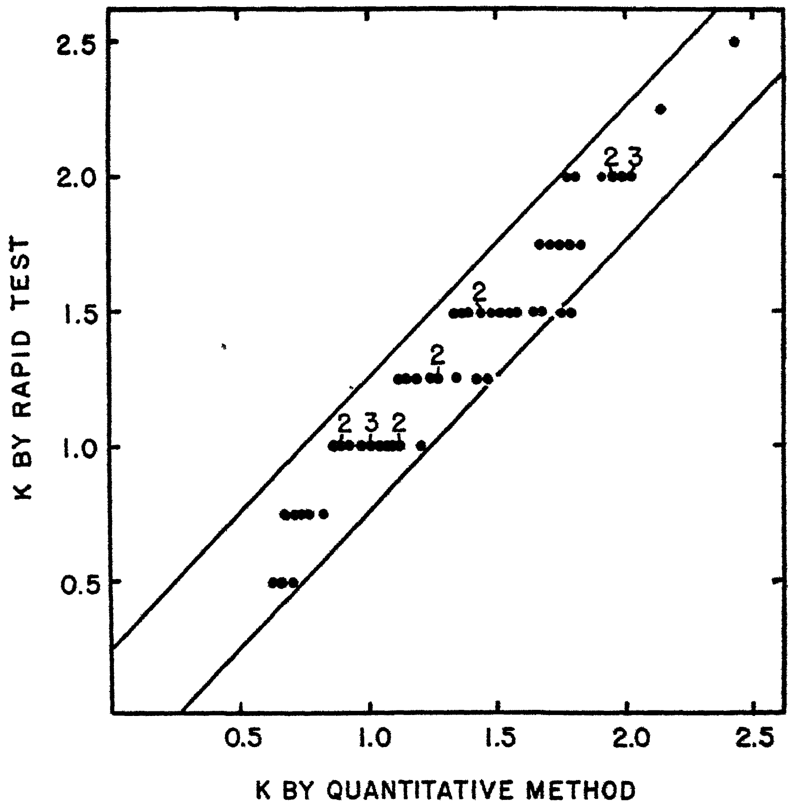

FIG. 1.—Potassium analyses of the same leaf samples by quantitative and rapid microchemical methods. Expressed as percentage of dry weight.

The following precautions were found necessary: (1) The blendor cups had to be thoroughly washed with the extracting solution before blending; otherwise, the first sample mixed in the cup that had been dry for some time was invariably low in magnesium, presumably caused by the interference of some heavy metal brought into solution from the blade assembly. (2) Addition of the activated carbon had to be deferred until the final minute of blending. When the carbon was added at the beginning of the 4-minute period of blending, the results for magnesium were sometimes low. (3) In the magnesium procedure, the standards containing the higher concentrations of

[5] *Loc. cit.*

magnesium tended to fade. It was necessary, therefore, to make the comparisons with a series of standards within 10 minutes after color development.

In Figs. 1 and 2, the results of rapid microchemical tests are plotted against those obtained by ashing at 500° C and subsequent

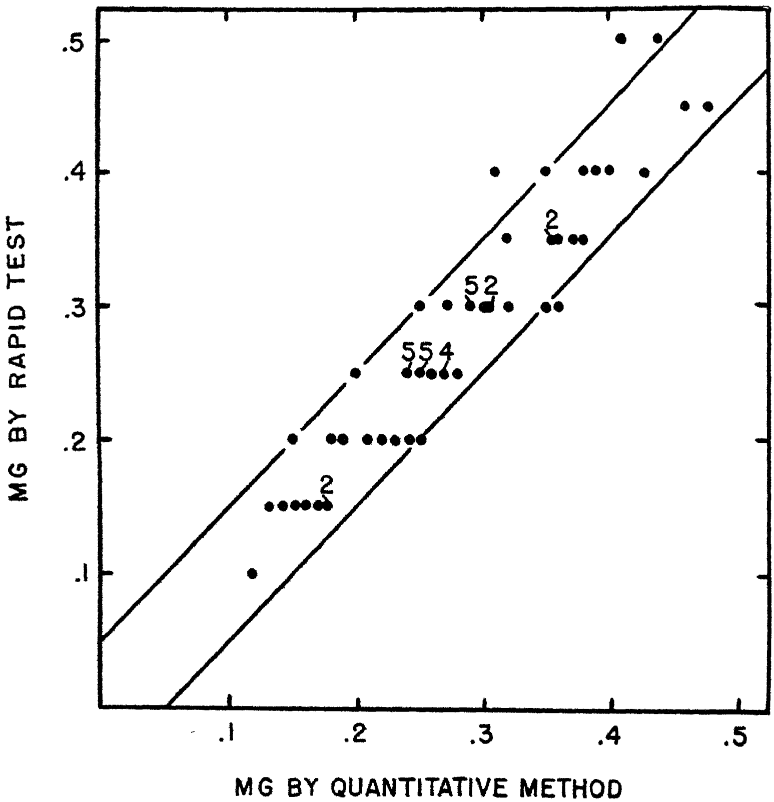

FIG. 2.—Magnesium analyses of the same leaf samples by quantitative and rapid microchemical methods. Expressed as percentage of dry weight.

analysis of the ash solution by the quantitative procedures. In all but one sample the results of potassium determinations by the rapid chemical test were within ±0.25% of those obtained by the quantitative method. Likewise, the agreement between the results of magnesium determinations as determined by the rapid chemical test and by the quantitative method was within ±0.05%, except for two samples that were high in magnesium.

Apple trees containing less than 0.75% of potassium in the leaves, dry weight basis, usually respond to potassium fertilization. McIntosh apple trees whose leaves contain 0.20% d.w. or less of magnesium usually respond to magnesium supplements when the magnesium content of the leaves is less than 0.20% on dry weight basis. Thus,

it would appear that the rapid chemical tests described by Peech and English are accurate enough to permit their use in diagnosing potassium and magnesium deficiency in apple trees.

How useful these tests will be for leaves of other kinds of plants remains to be seen. Thus far they have been applied successfully to grape and alfalfa leaves. However, with several samples of cherry leaves, it was impossible to obtain clear extracts. Although calcium does not interfere with the *p*-nitrobenzeneazoresorcinol test for magnesium on apple leaves, calcium interference may cause serious errors when analyzing plant material high in calcium. In this respect, the Titan yellow test for magnesium as given by Peech and English[6] may be superior to the *p*-nitrobenzeneazoresorcinol test.—DAMON BOYNTON and MICHAEL PEECH, *Cornell University, Ithaca, N. Y.*

[6] *Loc. cit.*

A PROBE FOR ESTABLISHING THE POSITION OF THE WATER SURFACE IN STANDPIPES

IN DRAINAGE investigations the need for following the position of the water table surface frequently arises. To accomplish this, standpipes of some sort are installed and the position of the phreatic surface in these pipes is measured periodically. If the water surface is some distance below the upper end of the pipe and if the diameter of the pipe is small, it is frequently difficult to measure accurately the position of the water surface. The device herein described enables an operator to determine with accuracy the water-table elevation in standpipes having a diameter of 1 inch or less.

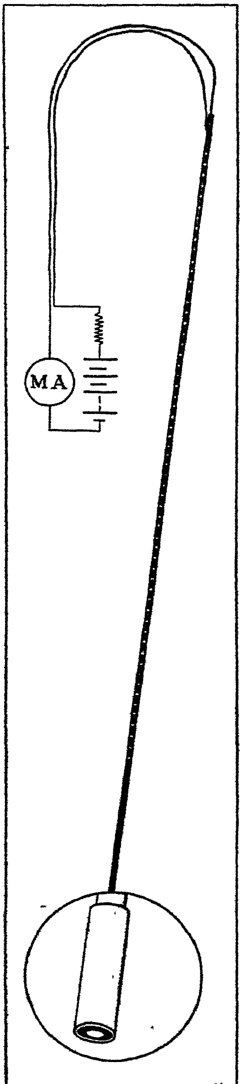

FIG. 1. — A probe for establishing the position of the water surface in sandpipes.

The measuring device consists of a graduated copper probe rod, a 45-volt battery, a 500-ohm resistor, and a small milliammeter. The construction and operation of the device can best be described with the aid of Fig. 1. The probe consists of a 5-foot length of ¼-inch copper tubing on which a scale graduated in 0.1-foot units is painted. One strand of a rubber-covered zip cord inside this tube is soldered to a small brass machine screw firmly embedded in a rubber insulator which in turn is incased in a 1-inch length of $\frac{5}{16}$-inch copper tubing soldered to the lower end of the probe. The second strand of the zip cord is soldered to the upper end of the copper probe. The 5-foot zip cord is connected serially through a 500-ohm resistor, a 45-volt "B" battery, and a small milliammeter. The resistor is provided to protect the milliammeter in the event of a short-circuit. The battery, resistor, and milliammeter can be mounted in a small box having inside dimensions of about 5×5×3.5 inches which can be placed on the ground near the standpipe while the probe is inserted in the pipe. When the lower end of the probe contacts the water surface, current flows through the circuit causing the needle of the milliammeter to deflect. The position of the water surface is then recorded in terms of the position of the probe scale and the top edge of the standpipe, which is the usual datum.

Two of these probes were used during the past year during which time over 3,000 measurements were made. No difficulty was experienced in reading the position of the water table to the nearest 0.05-foot in less than 15 seconds.—

M. B. RUSSELL, *Department of Agronomy, Iowa State College, and Division of Research, Soil Conservation Service, Ames, Iowa.*

BOOK REVIEW

SOIL SURVEY OF SOUTHERN SASKATCHEWAN

By J. Mitchell, H. C. Moss, and J. S. Clayton. University of Saskatchewan, Saskatoon, Saskatchewan: Soil Survey Report No. 12. VIII + 259 pages, illus. 1944. $1.00.

DOCTOR MITCHELL and his associates are to be highly complimented for a soil survey report that is refreshingly outstanding in both the scope and manner of presentation of soil data covering a large area. The report to an unusual degree is a combined account of the soil geography of southern Saskatchewan, a text on fundamental soil science, and a farmers' bulletin on soil management. An appreciation of the immensity of the work involved can perhaps be obtained when it is realized that the survey covers 96,000 square miles, an area approximately equal to that of Oregon, the ninth state in size in the United States. The map is published in four sections on a scale of 1 inch equals 6 miles.

As to be expected for an area of this size and published on the above scale, the survey is reconnaissance in nature rather than detailed. The authors explain that the methods of classification and mapping have been derived from the Russian school of soil science, the American system of soil survey, and the earlier surveys and studies carried on in Saskatchewan and the other prairie provinces of Canada. A marked feature is the use of "Soil Associations" as the basic unit of classification, mapping, and discussion. The use of "Soil Association" is taken from Manitoba and differs from its use here in the United States, as exemplified by soil maps in the U. S. D. A. 1938 Yearbook. The definition given in the report, "A local association of soil group profiles developed upon similar parent materials and belonging to the same soil zone", shows that the concept is similar to that of *catena* as used in the United States.

Descriptions of 42 soil associations occupy 119 pages. Each association is identified by a geographical name and described in terms of the nature of the parent geological material, the character of the individual kinds of profiles making up the association, and the appearance of the landscape, as conditioned by land use, topography, soil color, and vegetation. A detailed profile description is given of the dominant soil within each association, and the character of each of the associated members is indicated by such terms as *the solonetz member*, *the shallow knoll member*, *the poorly drained member*, and *the calcareous earth member*. A sub-heading, "Agriculture", discusses relations of the individual members of the association to land use and management.

The 42 associations are grouped in the report and on the map as classificational units of the zonal great soil groups or soil zones. Thus, there are 8 associations listed under the Brown soils, 8 under the Dark Brown soils, 12 under the Black soils, 7 under the Degraded Black soils, and 7 under the Grey (Podzol) soils.

Miscellaneous soils are grouped and discussed separately. They include Alluvium, Alkali (Saline) Soils, Peat (Bog) Soils, Dune

Sands and Undifferentiated Sands and Gravel Deposits, Eroded (Truncated) Soils, Depression (Bluff) Podzols, and Dissected Plateau Complex.

In addition to the more detailed discussion of individual soil association, the section "General Description of the Area" gives an excellent summary of the general topography, of drainage conditions, of surface geological deposits, and soil parent material, of the climate, the native vegetation, the natural resources, agricultural and nonagricultural, transportation and marketing facilities, and the history and development of the province.

The sections of "Soil and Plant Relationships" and "Soil Classification" are well written expositions of these aspects of soil science and justify the charge that the report is in part a text in fundamental soil science. Another special section of scientific interest is "Geology and its Relationship to Soils in Saskatchewan", prepared by Professor Edmunds.

Two sections, "Soils and Agriculture" and "Land Utilization and the Conservation of Land Resources", contain information on the relative suitability and grouping of the soils for wheat production, on the importance of a knowledge of soil conditions to farm management, and on the land resources of the entire province. The principal soil problems are discussed and presented under the subheadings soil erosion, soil fertility, commercial fertilizers, farm manure, summer fallow, and soil alkali.

A separate section, "The Composition of Saskatchewan Soils", and an Appendix with definition of soil textural classes, topographic classes, stony phases and soil structural aggregates, and tabular summaries of acreages of soil associations by topographical phases, important plant species, soil separates, and census data, illustrate further the tremendous amount of important information packed between the covers of this report.

Each of the four sheets of the map is complete with heading and legend. The different soil areas are separated by solid black boundary lines, and the kind of soil is identified on the map by the use of colors, letter combinations, and symbols. In general, the color of any particular portion of the map identifies the soil texture. The letter combinations indicate the soil association and textural class. The topographic classes and stoniness are shown by rulings and symbols. It is indeed unfortunate that the section lines are printed so heavily because they tend to dominate the map and overshadow and confuse the other information.

The entire text is very effectively illustrated by maps, drawings, and photographs.

It is to be noted that certain differences exist in the nomenclature between Saskatchewan and the United States. For example, the hard columnar structure referred to in the report is the prismatic structure of this country, whereas the columnar structure of this country is the round-topped columnar structure used in the report. Likewise, the terminology of the Great Soil Groups differs in that no reference is made to Chestnut and Chernozem—the established names in this country for the Dark Brown and Black soils of the

report. The classificational breakdown is somewhat different also in that the "soil member" appears to be comparable to the soil series of this country, although evidently no provision is made for the same soil member (such as the poorly drained member) to be recognized in more than one "soil association." In this country a few poorly drained soils appear in more than one catena.

To one who has spent some time in the Great Plains to the south across the international boundary, and to one who also has been concerned with the general form and content of soil survey reports, this report is particularly pleasing because of the comprehensive and balanced point of view evidenced by the authors and their able presentation of the information obtained by the survey. We are glad to recommend this report highly to readers of the JOURNAL despite our regret that the nomenclature in Saskatchewan and this country is not everywhere consistent.—J. KENNETH ABLEITER.

AGRONOMIC AFFAIRS

PROPOSED INTER-AMERICAN SOCIETY OF SOIL SCIENCE

AT THE Second Inter-American Conference of Agriculture held in Mexico City in July, 1942, a resolution was passed recommending that an Inter-American Society of Soil Science be organized. It also provided for a committee to draft the statutes for such an organization. The Mexican soil scientists Miguel Brambila and Antonio Rodriguez have drafted a constitution which will be proposed for adoption at the Third Inter-American Conference on Agriculture to be held in Caracas, Venezuela, in July, 1945.

The representatives of the United States to this Conference should have suggestions from their colleagues on this proposal. Copies of the proposed constitution are being mailed to the Executive Committte of the Soil Science Society of America and to the Joint-Committee on Cooperation with Foreign Scientists. Any other member of the Society who is interested in this proposal may obtain a copy of the constitution for examination by writing to Doctor Richard Bradfield, Department of Agronomy, Cornell University, Ithaca, New York.

NEWS ITEMS

ACCORDING TO *Science*, Doctor George H. Shull, Professor of Botany and Genetics, emeritus, of Princeton University, has received a citation of distinguished service from the New Jersey State Board of Agriculture in recognition of discoveries which led to the development of hybrid corn and for his years of service in the science of genetics at Princeton.

—A—

DOCTOR GILBEART H. COLLINGS, Professor of Soils at the Clemson Agricultural College, Clemson, S. C., has recently been reelected for the third time as President of the Pendleton Farmers Society. The Society is one of the oldest farmer organizations in the United States, having been founded in 1815.

Doctor J. B. Hester has resumed his work as Director of soil and nutritional research, Campbell's Soup Company, at Riverton, N. J. Doctor Hester returns to his duties after almost three years' service in the Army, which he entered as a First Lieutenant and in which he advanced to the grade of Major. Most of his service was in the Caribbean area.

—A—

Chester F. Hockley, President of The Davison Chemical Corporation, Baltimore, Md., announces the appointment of Charles J. Brand, for nearly 20 years chief executive officer and treasurer of The National Fertilizer Association and recently retired, as consultant to the President, effective May 1, 1945.

—A—

Doctor Robert E. Horton, hydraulic engineer and contributor to the Proceedings of the Soil Science Society, died at his home in Voorheesville, N. Y., on April 22 from a heart attack. He was 69 years of age.

—A—

The announcement in the April issue of the Journal regarding Doctor R. W. Cummings should have read Assistant Director rather than Director of the North Carolina Agricultural Experiment Station. Doctor L. D. Baver continues as Director of the Experiment Station and is also serving as Associate Dean and Director of Instruction in Agriculture. Doctor C. H. Bostian, Professor of Zoology (Genetics) and Poultry Geneticist for the Experiment Station, has been appointed Assistant Director of Instruction in Agriculture.

—A—

Professor E. V. Staker, formerly research agronomist at Cornell University, has been appointed agronomist in the Nebraska State Chemurgy Project at the University of Nebraska, Lincoln, Nebr.

JOURNAL

OF THE

American Society of Agronomy

VOL. 37 JUNE, 1945 No. 6

THE EFFECT OF CALCIUM ON YIELD AND QUALITY OF LARGE-SEEDED TYPE PEANUTS[1]

W. E. COLWELL AND N. C. BRADY[2]

ONE of the principal objectives in a research program concerned with the nutrition of peanuts is that of obtaining good kernel development, or, conversely, reducing the number of unfilled ovarian cavities ("pops").[3] Although the use of certain calcic materials has been known to be beneficial in the formation of well-developed kernels, their addition to soils of the peanut area of the southeastern states has not produced favorable results in many of the reported experiments. Furthermore, the effects reported from the use of limestone and gypsum as sources of calcium are quite different. Those working with the problem are continually confronted with certain inconsistencies in results that have been inadequately explained. These facts are well brought out by West's recent compilation of experimental results obtained in the southeastern states over a long period of years (5),[4] together with the two recent summaries of data obtained in North Carolina (2, 3).

The purpose of the present study was to investigate certain factors which affect the response obtained from large-seeded varieties of peanuts to calcium additions. Varietal differences with respect to calcium nutrition are to be reported in a subsequent paper. Results are reported from field experiments in which particular attention was given to (a) comparisons of two different practices used to supply calcium, (b) the placement of gypsum, and (c) chemical characteristics of the soils on which the experiments were located. Improved technics described in detail below were used to evaluate the behavior of the peanut plant to calcium variables.

---

[1]Contribution from the Department of Agronomy, North Carolina Agricultural Experiment Station, Raleigh, N. C. Published with the approval of the Director as Paper No. 202 of the Journal Series. Received for publication January 29, 1945.

[2]Associate Agronomist and Assistant in Agronomy, respectively. For the statistical analyses the authors are indebted to the Department of Experimental Statistics.

[3]A peanut fruit has one or more compartments, in each of which one kernel may form. An individual compartment is referred to as an ovarian cavity.

[4]Figures in parenthesis refer to "Literature Cited", p. 428.

MATERIALS AND METHODS

DESCRIPTION OF CALCIUM VARIABLES

The effects of limestone and gypsum on yield and quality of peanuts were studied on soils of widely different levels of exchangeable calcium. The limestone treatment in all cases consisted of the application of dolomitic limestone (52% $CaCO_3$, 40% $MgCO_3$ and around 50% passing a 100-mesh sieve) at the rate of 400 pounds per acre placed in the row at the time of planting. Unless otherwise specified, the gypsum treatment consisted of the application of commercial landplaster at the rate of 400 pounds per acre placed on the top of the row when the peanuts were in early bloom. Since differentials with respect to source, placement, and time of application are involved in these studies, the data provide only one strict comparison, that of the effects of two procedures used to supply calcium.

The experiments on placement of gypsum were conducted on soils known from previous experience to require calcium additions for adequate development of peanut fruit. Gypsum was added to two zones of the soil corresponding to the fruiting and rooting media of the plant. The fruiting medium is considered to be that portion of the soil in which fruit develop, usually the surface 2 to 4 inches. The area of soil below the zone of fruit development is referred to as the rooting medium. It is recognized, however, that there is no sharp boundary between these two zones.

In establishing placement differentials, the rooting zone application was made by placing gypsum 3 to 5 inches below the seed at the time of planting. The fruiting zone application was made by placing it on top of the row at the early blooming stage. Thus, a differential with respect to time of application as well as to placement of gypsum is involved in these comparisons.

MEASUREMENTS OF FRUIT QUALITY

In an attempt to obtain greater accuracy and precision in measuring fruit quality than the usual technics provide, a rather detailed classification was made of fruit picked from the vines by hand at the time of digging. From 10 to 20 plants were carefully removed from each plot, an attempt being made to select those not adjacent to a skip in stand. The fruits were detached immediately, bagged, and dried for several days in a heated barn. The samples were taken to the laboratory where all foreign material was removed. The fruits were broken open one at a time and classified according to the diagram in Fig. 1.

The number of ovarian cavities of each fruit was first determined. In most cases it was simply a matter of observation to determine if the number were three, two, or one. The next step was to determine, in a given fruit, the number of well-developed kernels, either three, two, one, or zero, and to place the kernel and shell separately in labeled beakers sitting in the appropriate positions on the table. Immature fruit were kept separate, as shown in the diagram. If any portion of the kernel or shell showed evidence of disease, both were placed in the diseased subdivisions.

After the fruit constituting a given sample had been classified, the number in each of the 24 categories was recorded. Although the numbers of immature fruit were obtained, they were not used in subsequent calculations. The total number of ovarian cavities or "kernel possibilities" from mature fruit in each sample was calculated. For example, if there were in the "3-cavity", the "2-cavity", and the "1-cavity" size groups, 20, 500 and 100 fruits, respectively, the total number of cavities would be $(3 \times 20) + (2 \times 500) + (1 \times 100)$, or 1,160. If out of this number of possibilities, there were a total of 464 well-developed kernels irrespective of distribution among the three fruit sizes, the percentage of cavities filled would be 40. In basing calculations on the total number of cavities instead of the number of fruit, proper weight was given to each of the fruit sizes.

The chief difficulty encountered in this classification was that of differentiating between fruits with immature kernels and those with ovules which had ceased developing ("pops"). Two features were used to facilitate this separation, color of the inside of the shell and kernel size. Dark veining on the inner sides of the shell and very small kernel size were considered evidence for classification as a "pop".

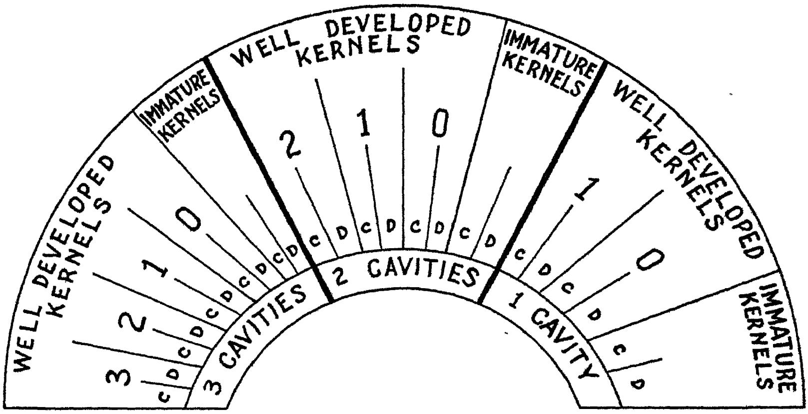

FIG. 1.—Diagram showing categories used in classifying peanut fruit. C and D refer to clean and diseased fruits, respectively.

The weight of kernels (mature only) from each of the separate subdivisions in the "2 cavity" and the "1 cavity" categories was recorded. The kernels from all subdivisions including those of the "3-cavity" fruit (not weighed separately) were then combined and the large and medium kernels[5] were separated from the remainder and weighed. By multiplying this value by 100 and dividing by the total weight of the clean unshelled samples, the "true shelling per cent" was obtained.

The procedure used in classifying fruit in 1942 differed somewhat from that described above. The fruits were obtained from the field in the same manner but were classified into one of the five following categories without regard to the number of cavities in a shell: (a) Well-developed fruit, (b) half "pop" (at least one empty cavity in the 2- and 3-cavity size groups), (c) "pops" (no well-developed kernels), (d) immature, and (e) diseased. The number of fruits in each category was determined and using as a basis the total number of fruits examined, the percentage of fruit in each category was calculated. True shelling percentages were calculated by the method already described.

MEASUREMENTS OF YIELD

When dug, the peanuts from each plot[6] were stacked separately and, after curing in the field, were threshed by a commercial picker. Plot yields were obtained by direct weighing of the threshed peanuts. As a means of adjusting yields to a uniform shelling percentage, samples of 500 to 1,000 grams were taken from each plot, weighed, cleaned, and then shelled by a small electrically powered sheller.[7] The "large and medium" kernels (4) were separated from the remainder of the sample by passing the shelled nuts over a screen with $\frac{15}{16} \times 1$ inch perforations. Their weight was divided by the weight of the entire weight of each sample, including trash. When expressed on a percentage basis, the quotient is termed

[5]Large and medium kernels are defined as those which do not pass through a screen having $\frac{15}{64} \times 1$ inch perforations. In shelling operations some of the large and medium kernels were broken and although the halves passed through the screen, their weight was added to that of those remaining on top.

[6]Plot size 1/50 acre at locations, ENE, WAT, HSE, UCP, JFM, DGC, and CLB; 1/100 acre at locations, RPF, FWR, ZRW, RD, MLW, and MPW. (Initials of cooperating growers.)

[7]The authors are indebted to J. D. Blickle and N. C. Teter, Department of Agricultural Engineering, North Carolina Agricultural Experiment Station, for their assistance in building the sheller used in this work.

"correction factor". In adjusting field weights to pounds per acre shelling 60% large and medium kernels, the following formula was used:

$$\text{Corrected yield (lbs./A)} = \frac{\text{Field weights (lbs./A)} \times \text{correction factor (\%)}}{60}.$$

The correction factor differs from true shelling percentage in that it is based on a machine-threshed sample containing considerable amounts of trash. When the variable trash content is considered together with the fact that many pops are blown out with the hay during threshing, it is evident that quality of peanut fruit is not accurately reflected by the correction factor.

ANALYTICAL METHODS[8]

Exchange properties of the soils were determined by an ammonium acetate procedure (Assoc. Off. Agr. Chemists) and are expressed as M.E. per 100 grams of soil. Phosphorus was extracted by 0.002N H_2SO_4 (Truog), and organic matter was determined by dry combustion (Assoc. Off. Agr. Chemists). The reported data are average values from four separate samples, each of which consisted of 20 portions of soil from the plow layer of the unfertilized plots.

RESULTS AND DISCUSSION

EFFECTS OF LIMESTONE AND GYPSUM TREATMENTS

In Table 1 are presented data obtained in 1942 on two soils, a Ruston sand and a Norfolk sandy loam. The former was one of low fertility level and low exchangeable calcium, 0.45 M. E. per 100 grams. The latter soil was one of higher fertility level and the exchangeable calcium content was 1.19 M. E. per 100 grams.

It will be noted that gypsum exerted a marked beneficial effect upon yield and quality of fruit. This was particularly pronounced on the soil lower in calcium. The limestone application, however, did not meet the calcium requirements of the fruit on the low calcium soil, and even on the soil higher in calcium it produced fruit of lower true shelling percentage than did gypsum.

Further comparisons on the effects of limestone and gypsum on yield and quality of peanut fruit were made in 1943 at four locations where the level of soil calcium varied from 0.21 to 1.15 M. E. per 100 grams. The results of these studies are reported in Tables 2 and 3. It will be noted that the gypsum treatment resulted in a marked increase in the yield and an improvement in the quality at all locations. It was far superior to the limestone treatment in this respect. As brought out in the 1942 results, the beneficial effect of gypsum is less pronounced on a soil of relatively high calcium level (1.15 M. E., location RD). Even here, however, kernel development was favored by added calcium. Data in Table 2, as well as those in Table 1, illustrate the inadequacy of the correction factor as a means of evaluating fruit quality. This was true for all experiments and reporting of all the correction factor data was considered unnecessary.

From five rotation experiments, more data are available to compare the effects of limestone and gypsum on yield and quality of

[8]Soil analyses were made under the supervision of J. R. Piland, Associate Soil Chemist.

large-seeded type peanuts.[9] These experiments were located on soils varying in exchangeable calcium from 0.59 to 2.21 M. E. per 100 grams.

TABLE 1.—*Effects of limestone and gypsum treatments on yield and quality of Virginia Bunch peanuts produced on two soils in 1942.**

Treatment	Total fruit examined	Percentage fruit		True shelling %	Correction factor %	Corrected yield, lbs. per acre	Soil analysis
		Well filled	Half "pops"				
				Ruston Sand (JFM)†			
Check......	2,992	1	9	12.6	32.5	359	pH =6.0
Gypsum...	3,702	31	28	55.2	58.0	1,669	Ex. cap. =2.66
Limestone..	835‡	4	19	26.2	34.4	612	Ex. Ca =0.45
							% Ca sat. =17
L.S.D. (.05)				7.1	26.2	373	Ex. Mg =0.18
							Ex. K =0.05
							% O.M. =1.0
							P, p.p.m. =32
				Norfolk Sandy Loam (DGC)			
Check......	1,386	19	21	34.3	57.0	1,479	pH =5.6
Gypsum....	956	43	24	65.4	66.0	1,642	Ex. cap. =3.4
Limestone..	955	27	27	43.1	63.0	1,707	Ex. Ca =1.19
							% Ca sat. =35
L.S.D. (.05)				25.0	None	None	Ex. Mg =0.26
							Ex. K =0.10
							% O.M. =1.2
							P, p.p.m. =88

*Two replications. One plot of each treatment except the check received a base application of 32 pounds of P_2O_5 from 16% superphosphate. Since the phosphate had no measurable effect upon yield or quality, the values of the two series were averaged.
†Initials of cooperating growers used to designate location.
‡Only one fourth as many plants taken from limestone plots.

Data from location ENE presented in Table 4 show the yield and quality of the Jumbo Runner variety as affected by calcium treatment on a soil with an exchangeable Ca content of 1.39 M. E. per 100 grams. Plots receiving gypsum produced fruit of a better quality and higher yields than those receiving limestone or left untreated. The beneficial effect of gypsum in 1943 is the most pronounced of any obtained during the 6-year period the experiment was in progress. The summer of 1943, from mid-July through August, when maximum fruit development occurred, was extremely dry. It is not known, however, whether these weather conditions were in part responsible for the response from supplementary additions of readily available calcium or whether a similar response may be regularly expected on a soil of this calcium level.

[9]Experiments initiated in 1938 by E. R. Collins and J. J. Skinner of the U. S. Dept. of Agriculture and completed in 1943.

TABLE 2.—*Effects of limestone and gypsum treatments on the yield and quality of Virginia Bunch peanuts produced on two soils in 1943.**

Treatment	Total cavities		True shelling %	Correction factor %	Corrected yield, lbs. per acre	Soil analysis
	Examined	% filled				
			Norfolk Loamy Sand (RPF)			
Check	2,180	16.3	28.3	40.6	271	pH =4.7
Gypsum	3,092	51.8	60.2	61.6	1,485	Ex. cap. =2.34
Gypsum†	3,316	46.1	55.5	57.1	1,698	Ex. Ca =0.21
Limestone†	2,872	24.8	39.9	49.1	547	% Ca sat. =9
						Ex. Mg =0.17
L.S.D. (.05)		6.7	8.4	11.7	356	Ex. K =0.04
L.S.D. (.01)		9.0	11.2	15.7	478	% O.M. =0.9
						P, p.p.m. =34
			Norfolk Sand (FWR)			
Check	2,372	12.5	28.5	46.4	373	pH =4.6
Gypsum	1,888	42.2	48.6	57.5	837	Ex. cap. =1.98
Gypsum†	2,012	39.0	49.7	60.1	1,186	Ex. Ca =0.54
Limestone†	2,540	12.7	28.5	46.5	333	% Ca sat. =27
						Ex. Mg =0.21
L.S.D. (.05)		9.1	8.2	4.8	238	Ex. K =0.04
L.S.D. (.01)		12.2	10.9	6.4	319	% O.M. =1.0
						P, p.p.m. =29

*Four replications.
†Base treatment of 45 pounds K_2O per acre.

Also shown in Table 4 are results obtained on a Ruston sandy loam having an exchangeable calcium level of 0.68 M. E. per 100 grams. Both the limestone and gypsum treatments improved the quality of peanut fruit, but only the limestone treatment significantly increased the yield. At least two factors are considered partly responsible for this behavior. First, the particular strain of Virginia Bunch peanuts, used in this experiment was a small-seeded type, which, from supplementary data obtained on varietal response to calcium,[10] would be expected to have a relatively low calcium requirement for normal fruit development. Second, there was severe leaf defoliation in this field which was particularly pronounced in the plots receiving gypsum. This may account for the higher yield of the plots receiving dolomitic limestone, particularly since good fruit quality was obtained by this treatment. The data are considered significant in that they bring out at least one set of conditions under which limestone treatment was superior to that of gypsum for the production of peanuts.[11]

[10]Discussed in a later report.

[11]The effect of magnesium contained in the dolomitic limestone is thought to be of minor significance since plants from plots receiving limestone plus gypsum were defoliated to the same degree as those receiving gypsum alone and yielded no higher. Had magnesium been directly responsible, the combination treatment might have been expected to result in yields higher than those obtained from the gypsum treatment.

TABLE 3.—*Effects of limestone and gypsum on the yield and quality of Virginia Bunch peanuts produced on two soils in 1943.**

Treatment	Total cavities		True shelling %	Corrected yield, lbs. per acre	Soil analysis
	Examined	% filled			
		Ruston Sandy Loam Deep Phase (ZRW)			
Check......	1,650	10.8	20.9	251	pH =5.1
Gypsum ...	1,959	41.0	55.4	1,155	Ex. cap. =2.78
Gypsum†...	1,878	38.9	51.6	1,603	Ex. Ca. =0.54
Limestone† .	2,292	19.4	35.6	466	% Ca sat. =17
					Ex. Mg =0.25
L.S.D. (.05)		8.5	8.0	701	Ex. K =0.04
L.S.D. (.01)		11.4	10.7	974	% O.M. =1.4
					P, p.p.m. =40
		Ruston Sand (RD)			
Check......	1,260	33.8	31.9	842	pH =5.6
Gypsum....	1,596	45.1	45.6	1,117	Ex. cap. =4.06
Gypsum†...	1,660	52.5	49.7	1,265	Ex. Ca =1.15
Limestone† .	2,160	14.6	24.3	442	% Ca sat. =28
					Ex. Mg =0.40
L.S.D. (.05)		13.0	4.0	292	Ex. K =0.12
L.S.D. (.01)		17.3	5.3	389	% O.M. =3.0
					P, p.p.m. =86

*Four replications for location RD, two for yield data from location ZRW, and three for quality data. Portion of last experiment lost. †Base treatment of 45 pounds K_2O per acre.

TABLE 4.—*Effects of limestone and gypsum treatments on the yield and quality of peanuts from rotation experiments at two locations in 1943.**

Treatment	Total cavities		True shelling %	Corrected yield, lbs. per acre	Soil analysis
	Examined	% filled			
		Dunbar-Lenoir Fine Sandy Loam (ENE)			
Check......	1,878	34.0	39.5	1,451	pH =5.5
Gypsum....	1,279	50.3	50.5	1,750	Ex. cap. =3.24
Limestone..	1,335	35.5	38.7	1,480	Ex. Ca =1.39
					% Ca sat. =43
L.S.D. (.05)		17.4	14.9	139	Ex. Mg =0.29
L.S.D. (.01)		26.3	22.6	185	Ex. K = .08
					% O.M. =1.2
					P, p.p.m. =60
		Ruston Sandy Loam (WAT)			
Check......	1,752	40.9	51.5	1,499	pH =5.5
Gypsum....	1,608	70.7	65.0	1,683	Ex. cap. =2.57
Limestone..	1,509	75.4	65.4	1,856	Ex. Ca =0.68
					% Ca sat. =26
L.S.D. (.05)		16.1	5.7	282	Ex. Mg = .22
L.S.D. (.05).		24.4	8.6	381	Ex. K = .07
					% O.M. = .9
					P, p.p.m. =31

*Three replications for quality records, six for yield. Jumbo Runner variety used at location ENE, a small strain of Virginia Bunch at WAT.

In Table 5 are presented the data from two rotation experiments in which the levels of calcium were greatly different. At location HSE, where the calcium content was 0.59 M. E. per 100 grams, the quality of peanuts was improved somewhat by the use of gypsum, although the yield was not appreciably affected by this treatment. The slight benefit of added calcium on this soil of relatively low calcium level may be due, at least in part, to the higher calcium level of the subsoil, 1.66 M. E. per 100 grams.

TABLE 5.—*Effects of gypsum on the yield and quality of Virginia Bunch peanuts from rotation experiments at two locations in 1942.*

Treatment	Total fruit examined	Percentage fruit		True shelling %	Corrected yield, lbs. per acre	Soil analysis
		Well filled	Half "pops"			
		Dunbar-Lenoir Fine Sandy Loam (HSE)				
Check.....	3,187	33.1	15.0	44.8	724	pH =5.1
Gypsum...	2,486	51.1	21.3	60.6	908	Ex. cap. =2.59
						Ex. Ca =0.59
L.S.D. (.05)		25.2		19.8		% Ca sat. =23
L.S.D. (.01)		41.8		32.8		Ex. Mg =0.24
						Ex. K =0.07
						% O.M. =0.7
						P, p.p.m. = trace
		Norfolk Fine Sandy Loam (UCP)				
Check.....	2,552	65.3	21.7	66.2	1,596	pH =5.6
Gypsum...	2,382	62.9	21.5	67.2	1,564	Ex. cap. =4.02
						Ex. Ca =2.21
						% Ca sat. =55
						Ex. Mg. =0.38
L.S.D......		None		None		Ex. K =0.10
						% O.M. =1.3
						P, p.p.m. =38

The calcium level at location UCP was extremely high, 2.21 M. E. per 100 grams, and it is of particular interest to note that gypsum was without effect upon either yield or quality of peanuts. Furthermore, no response was obtained from added calcium during any of the 6 years that the experiment was in progress. The true shelling percentage of the fruit produced in this soil in 1942 without the addition of calcium is higher than that of fruit produced on the gypsum-treated plots in any of the other experiments conducted. The value of maintaining a high calcium level in the soil instead of relying upon localized applications of either limestone or gypsum for each crop is brought out by these data.

PLACEMENT OF GYPSUM

The effect of gypsum placed in the rooting zone at the time of planting was compared to that exerted by an application made to the fruiting zone at the early blooming stage. The experiments

were conducted on soils known from previous experience to require added calcium for normal kernel development.

Data in Tables 6 and 7 show that gypsum placed in the fruiting area was more effective in the formation of good quality peanuts than that placed in the rooting area. The latter treatment, however, resulted in some improvement at one location. When the two placement treatments were combined, with a consequent application of 800 pounds per acre, yield and quality were higher than those obtained from either single application.

Strict comparisons on the effects of placement cannot be made since gypsum was applied at two different times. The effectiveness of the fruiting medium treatment, however, is in agreement with results of certain preliminary nutrient culture experiments conducted by Burkhart and Collins (1). They found gypsum applied in the fruiting zone to be important in kernel development. Their results have been substantiated by those from a somewhat more elaborate investigation conducted by the authors, the results of which are as yet unpublished.

TABLE 6.—*Effect of placement of gypsum on yield and quality of peanuts on Norfolk fine sandy loam, deep phase, in 1942 (CLB).**

Gypsum application†	Total fruit examined	Percentage fruit		True shelling %	Corrected yield, lbs. per acre	Soil analysis
		Well filled	Half "pops"			
None	2,057	9	12	24.9	364	pH =6.1
Rooting medium	2,915	19	24	40.5	878	Ex. cap. =2.10
Fruiting medium	2,593	49	15	52.9	1,595	Ex. Ca =0.21
						% Ca sat. = 10
L.S.D. (.05)		6.8		7.3	310	Ex. Mg =0.16
L.S.D. (.01)		9.1		9.9	417	Ex. K =0.06
						% O. M. =0.8
						P, p.p.m. =30

*Four replications.
†Rate = 400 pounds per acre.

Although the evidence has shown rather clearly the beneficial effect of calcium placed in the fruiting zone at the early blooming stage, it is apparent that the addition of gypsum in one of the experiments has completely eliminated the occurrence of unfilled fruit. For example, at one location (RPF) gypsum increased the yield from 271 to 1,485 pounds per acre, yet even with this treatment the percentage of cavities filled was only 51.8 (Table 2). In some experiments the value was still lower. Furthermore, only 65.3% of the fruit were filled at the location UCP where the exchangeable calcium level of the soil was 2.21 M. E. per 100 grams and where no response from added calcium was obtained (Table 5). It is apparent that the potential productive capacity of a given plant has not been reached.

TABLE 7.—*Effect of placement of gypsum on yield and quality of peanuts on Kalmia loamy sand in 1943 (MLW).**

Gypsum application†	Total cavities		True shelling %	Corrected yield, lbs. per acre	Soil analysis
	Examined	% filled			
None	3,284	26.5	31.7	419	pH = 5.3
Rooting medium	3,588	19.7	31.9	334	Ex. cap. = 3.13
Fruiting medium	3,360	59.8	60.3	842	Ex. Ca = .50
Both media	3,500	70.7	56.8	1,028	% Ca sat. = 16
					Ex. Mg = 0.27
L.S.D. (.05)		12.4	11.0	271	Ex. K = .12
L.S.D. (.01)		16.7	14.8	366	% O. M. = 1.1
					P, p.p.m. = 61

*Four replications.
†Rate = 400 pounds per acre.

SOIL ANALYSIS AS AN AID IN ACCOUNTING FOR RESPONSE FROM ADDED CALCIUM

Since the experiments were conducted on soils of widely different chemical characteristics, data are available to relate calcium response of large type peanuts to certain variables in soil composition. In evaluating the significance of the levels of exchangeable calcium, these values are plotted in Fig. 2 against check yields which are expressed in terms of percentage of those obtained with added calcium. This percentage value was used instead of absolute yield since it takes into account the differences in levels of soil productivity.

The correlation between the two sets of values is highly significant with an r value of 0.948. It should be kept in mind that the data were obtained from only a limited number of fields and further investigations are considered necessary to establish more exactly the relationship involved. There may be considerable practical use of such a relationship, however, even though the exact position of the curve may be found in subsequent studies to be somewhat different.

It will be noted that at one location where the level of calcium is 2.21 M. E. per 100 grams, no response was obtained from added calcium. It is likely that there may have been no response even if the calcium content were somewhat lower. For this reason the upper portion of the curve in Fig. 2, as well as in Figs. 3 and 4, is dotted and the point mentioned was not used in determining the correlation coefficients.

Percentage calcium saturation is plotted against check yields in terms of percentage of those obtained with added calcium in Fig. 3. A highly significant correlation was found between these two measures, but it was slightly poorer than that found with absolute level of calcium. The r value was 0.898.

In Fig. 4 are plotted calcium levels against percentage ovarian cavities filled in check plots in terms of percentage of those filled from gypsum-treated plots. A highly significant correlation was found between these values, the r value being 0.930.

The correlation coefficient between the measure of yield used above and pH was calculated and found to be only 0.182. It should be recalled that the exchange capacities of soils used in this investigation varied from 1.98 to 4.06 M. E. per 100 grams and it is not surprising to find a poor correlation between response and pH when calcium is the critical element.

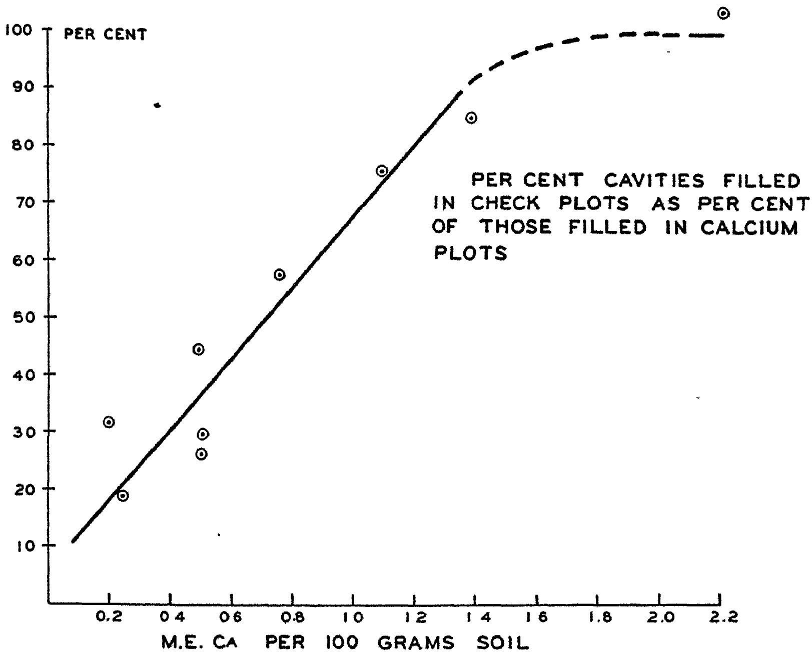

FIG. 2.—The relationship between a function of peanut yields and level of soil calcium.

CALCIUM TREATMENT AND VEGETATION

In none of the 12 experiments referred to was there any evidence that the original soil calcium was insufficient for normal vegetative growth. In fact, at half the locations, vegetation on the untreated plots was more abundant and of greener color than that on the gypsum-treated plots. At one location (HSE) quantitative data on stem length of untreated and gypsum-treated plants were obtained. A significantly greater total stem length per plant was found on those receiving no treatment. These observations, together with data already presented, are evidence that the effect of gypsum on the peanut plant is associated primarily with proper development of kernels, rather than an increase in the total number of fruit set.

Plants receiving the limestone treatment were somewhat larger and greener than those untreated at several locations. This vegetative response was particularly noticeable during early and midsummer, but was reflected in yield at only one location (WAT).

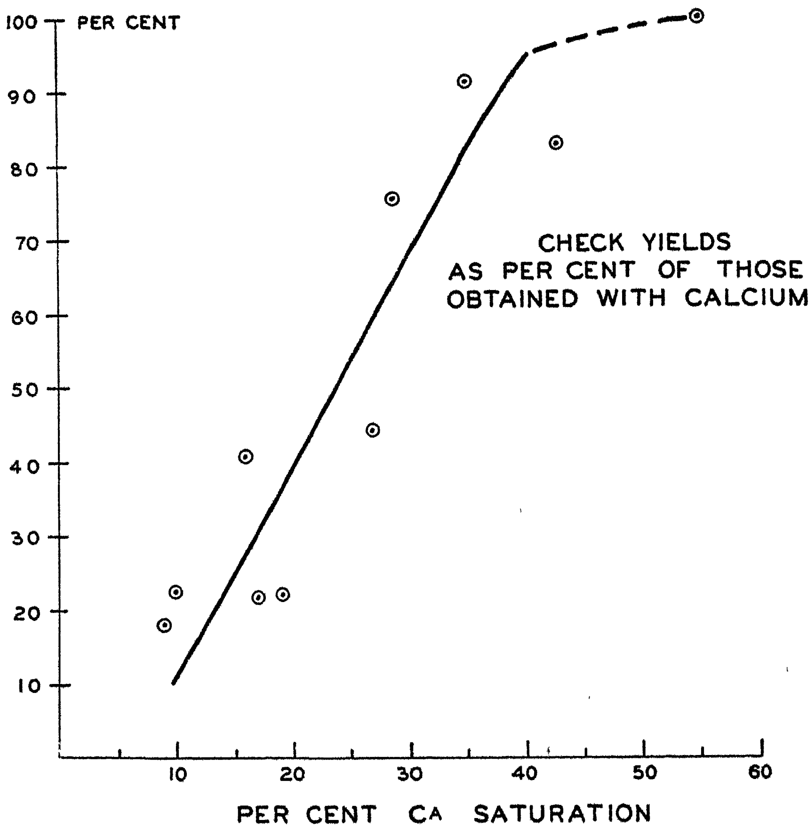

FIG. 3.—The relationship between a function of peanut yields and percentage calcium saturation of certain soils.

EFFECT OF CALCIUM TREATMENT ON SOIL CHARACTERISTICS

To study the effects of limestone and gypsum added at rates common in peanut fertilization on pH, calcium, and magnesium levels of the soil, two approaches were used. One consisted of analyzing the soil which was in immediate contact with peanut fruit at the time of digging. A sample consisting of 20 portions of soil was taken from each plot of four experiments in which a definite response to added calcium was obtained. The results of these analyses are presented in Table 8.

Two principal facts are shown by the data. The calcium levels of the soils have not been raised by gypsum or limestone applications to a level found in other experiments to be adequate for good fruit development, yet on the gypsum-treated plots it has been shown that good quality fruit was produced (Tables 2, 3, 6, 7). In all probability the concentration of calcium ions in solution on the gypsum-treated plots was, at some time during the period of fruit

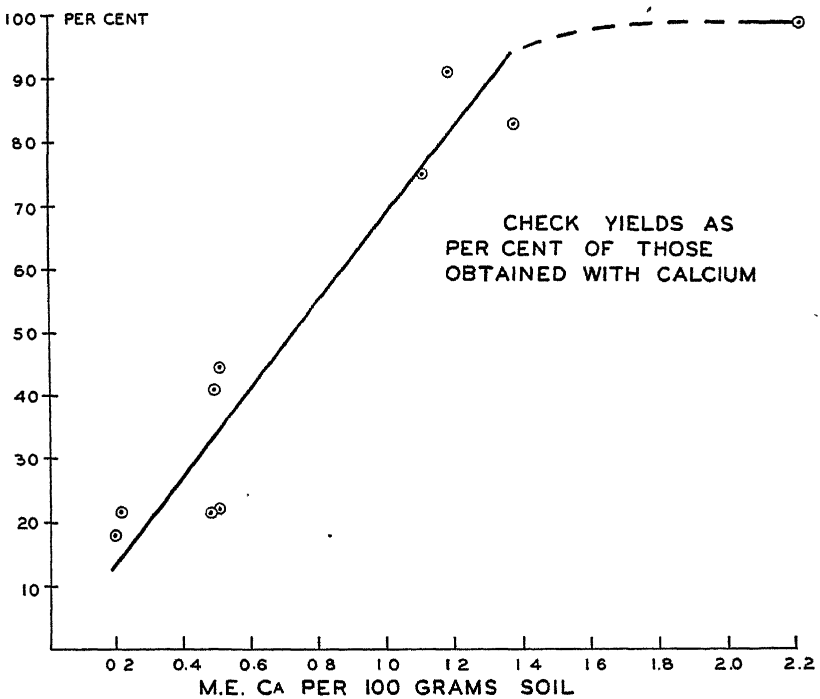

FIG. 4.—The relationship between a function of percentage ovarian cavities and level of soil calcium.

development, higher than that which one might expect from the exchange values found in these soils at the end of the season. A high concentration of calcium ions for even a short period may have been sufficient for normal fruit development. This postulation is based upon unpublished results which show that if calcium is supplied to the fruiting medium for as short a period as 3 weeks during the early stages of development, normal filling of fruit will take place even though the supply of calcium is then withdrawn completely.

A second feature of special interest is the relatively high exchangeable calcium level found in the soils receiving limestone compared to that found in the soils receiving gypsum, particularly since the quality of fruit obtained with the lime treatment was much lower than that obtained from the application of gypsum. It may be assumed that in spite of the higher exchangeable calcium level in the limestone plots, a sufficiently high concentration of calcium ions was not available during the critical period of fruit development.

Although the magnitude of differences brought about by calcium additions is not large, certain of them are statistically significant, particularly the calcium level at location MLW where gypsum was added to both the rooting and fruiting zones. The magnesium level was raised by the application of limestone at the two locations where it was applied.

TABLE 8.—*Effect of gypsum and limestone treatments on pH and calcium level of the soil at the end of the growing season at each of four locations.*

Treatment	pH	Ex. Ca, M.E. per 100 grams	Ex. Mg, M.E. per 100 grams
Ruston Sand (RD)			
Check	5.5	1.29	0.32
Gypsum*	5.9	1.75	0.30
Limestone*	6.0	1.94	0.54
Norfolk Loamy Sand (RPF)			
Check	5.3	0.31	0.15
Gypsum*	5.1	0.36	0.12
Limestone*	5.8	0.48	0.20
Kalmia Loamy Sand (MLW)			
Check	5.2	0.52	0.31
Gypsum:			
Fruiting medium	5.1	0.64	0.19
Rooting medium	5.2	0.61	0.28
Both media	5.2	0.71	0.24
L.S.D. (.05)	0.12	0.15	0.09
L.S.D. (.01)	0.16	0.20	0.12
Norfolk Fine Sandy Loam, Deep Phase (CLB)			
Check	6.1	0.21	0.16
Gypsum:			
Fruiting medium	6.3	0.34	
Rooting medium	6.4	0.26	
L.S.D. (.05)	—	0.09	
L.S.D. (.01)	—	0.12	

*Base applications of 45 pounds K_2O per acre.

The second approach used to study the effects of limestone and gypsum upon the pH, calcium, and magnesium levels of soils was made by analyzing soils from selected plots from four of the rotation experiments to which reference has already been made. In the particular block sampled, dolomitic limestone and gypsum were added separately at the rate of 400 pounds per acre to peanuts in 1938 and again to the same plots in 1941. The plots were uniformly fertilized during intervening years when soybeans and cotton were planted in succession. In October, 1943, samples of surface soil were taken from three plots of each treatment from the four rotation experiments. The results are presented in Table 9.

The analyses show that the limestone has raised the pH, calcium, and magnesium considerably more than did gypsum. Even though certain of these changes are significant, with odds greater than 19:1, none are of an appreciable order of magnitude. The trend is in line with predictions made on a basis of the soil chemistry involved and illustrates the value of a basic source of calcium in raising the calcium level of the soil.

TABLE 9.—*Effect of gypsum and limestone treatment on pH, calcium, and magnesium levels of soils at the end of rotation experiments conducted for 6 years.*

Treatment	pH	Ex. Ca, M.E. per 100 grams	Ex. Mg, M.E. per 100 grams
Ruston Sandy Loam (WAT)			
Check	5.6	0.62	0.13
Gypsum	5.9	0.62	0.12
Limestone	6.0	0.79	0.16
L.S.D. (.05)	0.35	0.17	0.04
L.S.D. (.01)	0.57	0.28	0.06
Dunbar-Lenoir Fine Sandy Loam (ENE)			
Check	5.4	1.28	0.29
Gypsum	5.4	1.41	0.29
Limestone	5.6	1.42	0.34
L.S.D. (.05)	0.48	0.72	0.06
L.S.D. (.01)	0.79	1.19	0.10
Wickham Sandy Loam (JGS)			
Check	5.2	0.79	0.28
Gypsum	5.4	0.83	0.30
Limestone	5.7	0.91	0.39
L.S.D. (.05)	0.27	0.22	0.26
L.S.D. (.01)	0.62	0.51	0.60
Dunbar-Lenoir Fine Sandy Loam (HSE)			
Check	4.9	0.45	0.17
Gypsum	4.8	0.44	0.23
Limestone	5.1	0.51	0.19
L.S.D. (.05)	0.33	0.16	0.17
L.S.D. (.01)	0.54	0.27	0.28

SUMMARY AND CONCLUSIONS

Large-seeded type peanuts, principally of the Virginia Bunch variety, were grown in the field on soils of widely different levels of calcium. Variables with respect to calcium fertilization were introduced and their effects upon yield and quality of fruit were determined.

To increase accuracy in obtaining a measure of fruit quality, use was made of a rather detailed system of classification. Essentially, it consisted of classifying fruit taken directly from plants in the field, on the basis of kernel development, and determining the percentage of ovarian cavities which were filled. True shelling percentages on a weight basis were calculated from data obtained on samples classified in this manner.

Comparisons were made between the effects of dolomitic limestone placed in the row at time of planting and gypsum placed on top of the row at the time of early bloom. The gypsum treatment was far superior in meeting the calcium requirements of peanut

fruit produced on soils, the calcium content of which varied from 0.21 to 1.39 M. E. Ca per 100 grams. On one soil with a calcium content of 2.21 M. E. per 100 grams, a high yield of good quality fruit was produced without supplementary calcium. The magnitude of the response from calcium was greater on soils of lowest calcium level, as shown by the high correlation coefficients between calcium content (0.948) of the soil or percentage calcium saturation (0.898) and check yields in terms of percentage of yields obtained with added calcium. The corresponding value for pH was only 0.182.

On two soils of low calcium level which were known from previous experience to require added calcium for the production of fruit of good quality, it was found that gypsum added to the fruiting zone of the soil at early blooming improved yield and quality whereas that added in the rooting medium at planting time did not. The beneficial effects of the fruiting medium treatment are in agreement with those obtained under controlled conditions of placement in nutrient culture investigations.

Even though a marked improvement in quality was brought about by the addition of gypsum to the fruiting medium, it is evident that the potential productive capacity of a given plant has not been reached since even with this treatment from 30 to 60% of the ovarian cavities remain unfilled.

At the end of the growing season it was found that differences in the calcium contents of soil in immediate contact with the fruit from different plots were small and inadequate to account for the observed responses. It is postulated that at some time during the period of fruit development the concentration of calcium ions was much higher than that expected from the analyses made at the end of the season.

Results of the investigation show that calcium is an element of major importance in the nutrition of large-seeded type peanuts, and, although a very low level of soil calcium is adequate for vegetative growth, a relatively large supply is necessary for proper development of fruit.

From the standpoint of practical production, the results of this study reveal that an adequate soil fertility program for peanuts should be one in which attention is directed toward raising the calcium content of the soil to a level adequate for the development of peanut fruit, provided this level is not unsatisfactory for other crops in the rotation. If it is impractical to raise the calcium level of the soil to this point, localized applications of a relatively soluble calcium salt, such as gypsum, may be made with advantage.

LITERATURE CITED

1. BURKHART, LELAND, and COLLINS, E. R. Mineral nutrients in peanut plant growth. Soil Sci. Soc. Amer. Proc., 6:272–280. 1942.
2. COLLINS, E. R., and MORRIS, H. D. Soil fertility studies with peanuts. N. C. Agr. Exp. Sta. Bul. 330. 1941.
3. COLWELL, W. E., and BRADY, N. C. Soil fertility studies with peanuts. N. C. State Dept. Agr. Bul., Sept. 1943.
4. KITCHEN, C. W. U. S. standards for farmers' stock Virginia type peanuts. Mimeo release issued Oct. 3, 1934; reissued Jan. 26, 1940.
5. WEST, H. O. Peanut production. Miss. Agr. Exp. Sta. Bul. 366. 1942.

YIELD AND QUALITY OF LARGE-SEEDED TYPE PEANUTS AS AFFECTED BY POTASSIUM AND CERTAIN COMBINATIONS OF POTASSIUM, MAGNESIUM, AND CALCIUM[1]

N. C. BRADY AND W. E. COLWELL[2]

THE importance of calcium in the proper kernel development of large-seeded type peanuts has been discussed in an earlier paper (3).[3] The following report is concerned with the effects of potassium and various combinations of potassium, magnesium, and calcium on kernel development.

The limited information available concerning the effects of potassium on peanuts suggests that the addition of this element is unfavorable for kernel development. For example, the use of potassium has been found to limit the filling of fruit in solution culture experiments (1), and to lower shelling percentages in field experiments (2). In some field experiments, however, this element has been found to increase yields, but the increases occur infrequently and are usually not large (2, 5).

An inevitable potash problem on soils regularly cropped to peanuts is readily recognized when this general lack of response is considered along with two additional facts, *viz.*, (a) the removal of potassium by a crop of peanuts is very large, about 75 pounds K_2O being lost when the hay and fruit of a crop yielding 1,500 pounds per acre of unshelled nuts are removed (2); and (b) the potassium content of most peanut soils in North Carolina is very low as shown in a recent summary of soil analyses compiled by Reed (4). The range of exchangeable potassium in the 14 soils used in the present investigation was from 0.04 to 0.19 M. E. K per 100 grams, while the average was only 0.08 M. E. per 100 grams.

The major objective of the present investigation was to study the effects of potassium on kernel development and yields of large type peanuts in field experiments located on soils of widely different chemical characteristics. As a part of this study, calcium was added along with potassium in several of the experiments since the former element was found to be limiting for normal kernel development on many of the soils.

The magnesium content of many peanut soils is very low and inasmuch as little is known regarding the specific effect of this element on kernel development, the work was extended to include a study of the effects of magnesium treatments.

Thus, the data reported here provide information on the effects of potassium alone and in placement combinations with magnesium or calcium. At the same time, results are available to show the effects of certain magnesium and calcium combinations. Particular atten-

[1]Contribution from the Department of Agronomy, North Carolina Agricultural Experiment Station, Raleigh, N. C. Published with the approval of the Director as Paper No. 203 of the Journal Series. Received for publication January 29, 1945.

[2]Assistant in Agronomy and Associate Agronomist, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 442.

changeable potassium levels ranging from 0.05 (JFM) to 0.19 (JGS) M. E. K per 100 grams. In fact, the use of potassium in one of the experiments was found to decrease the yield.

EFFECTS OF POTASSIUM ALONE AND IN COMBINATION WITH CALCIUM OR MAGNESIUM

The importance of separate consideration of the nutrient requirements of the rooting and fruiting media has been brought out in previous studies with calcium (1, 3). In view of this fact, it was considered advisable to investigate the effect of placing potassium in the two soil zones of plant development, both in the presence and absence of added calcium.

In the initial investigation either muriate of potash or potassium metaphosphate to supply 45 pounds of K_2O per acre was placed either in the rooting zone at planting time or in the fruiting zone at the early blooming stage. The gypsum was added in either the rooting or the fruiting medium at the rate of 400 pounds per acre. The specific treatment combinations are listed in Table 4 together with the data on yield and quality of fruit.

TABLE 1.—*Effect of potash on yield and quality of Virginia Bunch peanuts produced on two soils in 1942.**

Treatment	Total fruit		True shelling %	Corrected yield, lbs. per acre	Soil analysis
	Examined	% filled			
	Ruston Sand (JFM)†				
Check	2,992	0.9	12.6	360	pH =6.0
30 lbs. K_2O‡	1,065	1.8	16.5	460	Ex. cap. =2.66
Gypsum	3,702	30.8	55.2	1,670	Ex. Ca =0.45
					Ex. Mg =0.18
Limestone	835	4.2	26.2	612	Ex. K =0.05
Limestone+30 lbs. K_2O	1,132	8.3	27.3	719	
L.S.D. (.05)		8.1	7.1	373	
	Norfolk Sandy Loam (DGC)				
Check	1,386	18.6	43.4	1,180	pH =5.6
30 lbs. K_2O	1,091	18.8	33.6	1,475	Ex. cap. =3.4
Gypsum	956	42.7	65.4	1,642	Ex. Ca =1.19
					Ex. Mg =0.26
Limestone	955	26.8	43.1	1,707	Ex. K =0.10
Limestone+30 lbs. K_2O	661	23.8	42.5	1,510	
L.S.D. (.05)			25.0		

*Two replications.
†Initials of cooperating growers.
‡Approximately four times as many plants were taken from the gypsum and check plots.

TABLE 2.—*Effect of potash on yield and quality of Virginia Bunch peanuts produced on two soils in 1942.**

Treatment	Total fruit		True shelling %	Corrected yield, lbs. per acre	Soil analysis
	Examined	% filled			
Dunbar-Lenoir Fine Sandy Loam (HSE)					
Check	3,187	33.1	44.8	635	pH =5.08
48 lbs. K_2O	3,269	30.3	47.4	633	Ex. cap. =2.59
Gypsum	2,486	51.1	60.6	826	Ex. Ca =0.59
					Ex. Mg =0.24
L.S.D. (.05)		25.2	19.8	230	Ex. K =0.07
Norfolk Fine Sandy Loam (UCP)					
Check	2,552	65.3	66.2	1,572	pH =5.57
48 lbs. K_2O	2,434	64.6	67.1	1,616	Ex. cap. =4.02
Gypsum	2,382	62.9	67.2	1,574	Ex. Ca =2.21
					Ex. Mg =0.38
L.S.D.		None	None		Ex. K =0.10
Dunbar-Lenoir Fine Sandy Loam (ENE)					
Check	1,878	34.0	39.5	1,451	pH =5.5
48 lbs. K_2O	2,395	23.3	30.7	1,299	Ex. cap. =3.24
Gypsum	1,279	50.3	50.5	1,750	Ex. Ca =1.39
					Ex. Mg =0.29
L.S.D. (.05)		17.4	14.9	139	Ex. K =0.08
Ruston Sandy Loam (WAT)					
Check	1,752	40.9	51.5	1.499	pH =5.5
48 lbs. K_2O	2,193	49.7	56.8	1,411	Ex. cap. =2.57
Gypsum	1,608	70.7	65.0	1,683	Ex. Ca =0.68
					Ex. Mg =0.22
L.S.D. (.05)		16.1	5.7	282	Ex. K =0.07

*Three replications for quality records, six for yield.

TABLE 3.—*Six-year average yields in pounds per acre with increases from applications of potash at five locations, 1938–43.**

Treatment†	Soil type and location designation				
	Ruston sandy loam (WAT)	Dunbar-Lenoir fine sandy loam (ENE)	Dunbar-Lenoir fine sandy loam (HSE)	Wickham sandy loam (JGS)	Norfolk fine sandy loam (UCP)
Check	1,356	1,470	668	1,373	1,462
Increase from high K	-9	40	-21	1	92
Increase from low K	-74	3	-31	-38	194
L.S.D. (.05)	204	99	—	107	193

*Averages of six replications.
†High K = 48 pounds K_2O, 1940–43, inclusive; 36 pounds K_2O, 1938–39, inclusive. Low K = Half of these quantities.

TABLE 4.—*Effect of placement of potassium with and without calcium upon yield and quality of Virginia Bunch peanuts on a Norfolk sandy loam, deep phase, in 1942 (CLB).**

Treatment		Total fruit		True shelling %	Corrected yield, lbs. per acre	Soil analysis
Rooting medium	Fruiting medium	Examined	% filled			
None	None	2,057	8.5	24.9	364	pH =6.1
KCl	None	2,515	4.8	17.1	312	Ex. Cap. =2.10
None	KCl	2,506	9.5	24.0	264	Ex. Ca = .21
						Ex. Mg = .16
None	Gypsum	2,593	49.3	52.9	1,595	Ex. K = .06
KCl	Gypsum	2,353	39.7	53.5	1,402	
Gypsum	None	2,915	18.7	40.5	878	
Gypsum	KCl	3,105	14.1	23.4	603	
None	KPO_3	2,652	6.9	16.5	450	
KPO_3	None	2,861	7.6	20.8	351	
	L.S.D. (.05)		6.8	7.3	310	
	(.01)		9.1	9.9	417	

*Four replications.

Potassium exerted no beneficial effects on yield or quality in any of the treatment combinations used in this experiment. On the other hand, it tended to lower fruit quality, particularly when placed in the rooting zone without calcium. Also, potassium reduced quality when placed in the fruiting medium in combination with a rooting medium of application of calcium, the latter treatment not having met the calcium requirements of the fruit.

To investigate the effect of potassium placement in greater detail, the following year, 1943, these studies were repeated with certain modifications. The experiment was enlarged to include magnesium and the sulfates of the three cations were used in an attempt to measure more nearly the effects of cations only. The following treatments to the rooting medium were made at the time of planting: (a) No treatment, (b) K_2SO_4 (48 pounds K_2O), (c) $MgSO_4 \cdot H_2O$ (15 pounds MgO), (d) $CaSO_4 \cdot 2H_2O$, (130 pounds CaO). The materials were placed 3 to 5 inches below the level of the seed. Upon each of these rooting medium treatments, four fruiting medium treatments were superimposed by using the above materials, at the same rates, and making applications at the early blooming stage (July 5). In this way 16 treatment combinations were established. The experimental design used was a simple lattice of four replications.

The soil selected for the study (location MLW) was a Kalmia sandy loam which, when untreated, was known to produce peanuts of poor quality. Certain chemical characteristics of the soil are pH 5.3; exchange capacity 3.13 M. E. per 100 grams; and exchangeable Ca, Mg, and K, 0.50, 0.27, and 0.12 M. E. per 100 grams, respectively.

The most striking features of the results, presented in Figs. 1, 2,

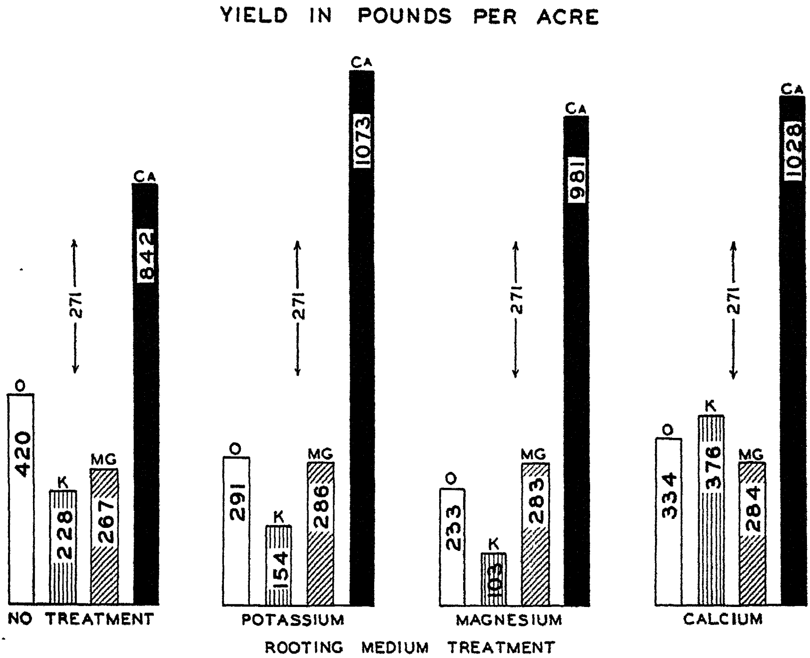

FIG. 1.—The effect of fruiting medium treatments, indicated by symbols on top of the bars, superimposed on rooting medium treatments as indicated, on the yield of Virginia Bunch peanuts. Least significant difference (.05) shown by arrows.

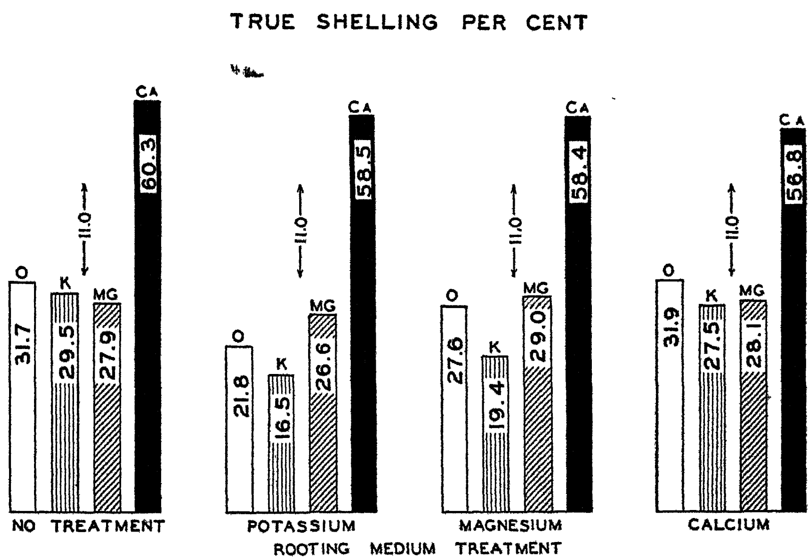

FIG. 2.—True shelling percentage as affected by fruiting medium treatments superimposed on rooting medium treatments as indicated. Least significant difference (.01) shown by arrows.

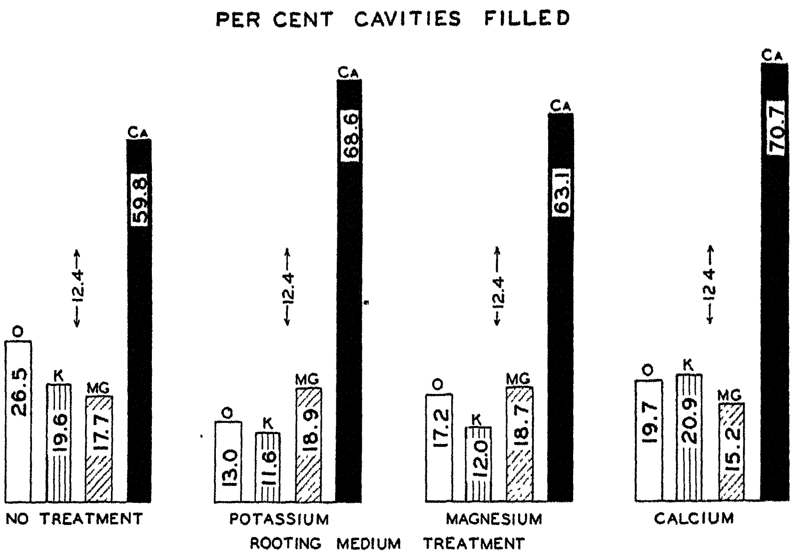

FIG. 3.—Percentage ovarian cavities filled as affected by fruiting medium treatments superimposed on rooting medium treatments as indicated. Least significant difference (.01) shown by arrows.

and 3, are the pronounced responses from gypsum applied in the fruiting medium. Quality and yield were significantly increased by this treatment irrespective of the treatment made to the rooting zone. The calcium requirements of the fruit were not met, however, by the application of gypsum to the rooting zone only.

There was no significant response from the use of magnesium in the zone of fruit formation. When placed in the rooting zone, in combination with potassium in the fruiting medium, it resulted in significant decreases in yield and quality. In general, the magnesium treatments had an unfavorable effect on kernel development and did not increase yields even when the calcium requirements were met.

Some rather interesting results from potassium were obtained in this experiment. If the effects of this element placed in the rooting medium are first considered, it will be noted that in comparison with the plots receiving no fertilization in either zone, potassium (a) significantly lowered quality whenever the fruiting medium received potassium or was left untreated, (b) it has significantly lowered yield when the accompanying fruiting medium treatment was potassium, and (c) it slightly lowered both quality and yield with an accompanying fruiting medium treatment of magnesium. With the fruiting medium treatment of calcium, the use of potassium in the rooting zone did not lower the relatively high yields or quality of fruit resulting from the calcium treatment.

When the effects of the fruiting medium application of potassium are compared with those obtained from plots receiving no fertilization in either zone, it can be seen that potassium (a) significantly

lowered quality and yield when the accompanying rooting medium treatment was potassium or magnesium, and (b) slightly lowered the quality and yield when the rooting medium received either no treatment or an application of calcium.

From the standpoint of practical production of peanuts, the results point out some rather significant aspects relating to direct fertilization with potash. They show, for example, that a poor combination is one in which potassium is placed in the fruiting medium with either potassium or magnesium in the rooting zone. They show, too, that good kernel development obtained by the addition of calcium to the fruiting area is not affected by the application of potassium to the rooting zone. These results illustrate the point previously referred to, namely, that the true effects of potash cannot be measured so long as production is limited by the lack of any other element or elements.

QUALITY AS AFFECTED BY VARIOUS QUANTITIES OF POTASSIUM AND CALCIUM IN THE FRUITING MEDIUM

A question of importance unanswered by the above data is the effect of potassium in the fruiting medium when used with and without added calcium in the same zone. This is of practical significance since it is a common practice to add to this zone various mixtures containing both potassium and calcium, and from the data just presented there is reason to believe that the practice of applying potassium to the fruiting medium may not be one most favorable for the production of high-quality fruit.

To obtain information on this problem, an experiment was conducted to compare the effects of three rates of muriate of potash applied with gypsum at the rates of 400 and 800 pounds per acre. Two salts were thoroughly mixed and applied to the fruiting zone on July 7, at the time of early bloom. The soil selected for this study was a Norfolk coarse loamy sand.

Data on true shelling percentage and percentage ovarian cavities filled are shown in Table 5. Since the yields from all plots were extremely low, due primarily to a poor stand, these data are not included. It will be noted that potash did not affect the quality of fruit when used in the presence of gypsum. Without gypsum, however, the application of 62 pounds K_2O per acre tended to lower both true shelling percentage and percentage ovarian cavities filled. It would appear, therefore, that any possible unfavorable effects of potassium applied to this zone might easily be overcome by simultaneous additions of calcium.

RESPONSE TO POTASH ON SOILS OF LOW POTASSIUM LEVEL

In most of the soils used in the experiments reported, it has been shown that calcium was a limiting factor for normal kernel development. Since potassium is not beneficial in the filling of fruit, it is logical to assume that its effect or that of any other element failing to aid in kernel development, cannot be determined with confidence until the calcium requirement is met. The results from location MLW,

which have already been discussed, show that the effect of potash on yield was markedly different when the calcium requirement had been met.

TABLE 5.—*The quality of peanut fruit produced on a Norfolk loamy coarse sand as affected by potassium and calcium applied to the zone of fruit development, 1943 (MPW).*

Treatment		Total cavities		True shelling %	Soil analysis
K_2 per acre, lbs.	Gypsum per acre, lbs.	No. examined	% filled		
None	None	2,828	19.0	24.6	pH = 5.3
20	None	2,356	16.8	20.5	Ex. cap. = 1.94
42	None	2,068	17.5	21.8	Ex. Ca = 0.44
62	None	2,344	13.1	17.6	Ex. Mg = 0.19
					Ex. K = 0.07
None	400	2,324	30.8	29.7	
20	400	2,700	32.1	32.7	
42	400	2,696	33.0	36.4	
62	400	2,576	26.9	31.2	
None	800	2,562	33.8	35.4	
20	800	2,804	31.8	34.8	
42	800	2,372	36.0	36.0	
62	800	2,472	33.5	34.6	
L.S.D. (.05)			9.9	7.7	

To obtain further information on the effects of potash in the presence of calcium on soils of low fertility, four experiments were conducted in 1943 on soils ranging in their levels of exchangeable potassium from 0.04 to 0.12 M. E. In these experiments, potassium was used with gypsum and with dolomitic limestone. The potash treatment consisted of the application of 45 pounds K_2O per acre from muriate of potash at the time of emergence. Gypsum was added at the rate of 400 pounds per acre at early bloom, and limestone was added at the same rate in the row at the time of planting. Previous cropping histories and fertilization practices differed considerably at the four locations.[9] Relatively heavy additions of potash had been made at location RD, and at the other locations potassium fertilization had been light. Yield and quality records were taken

[9]At location RPF, the 1942 and 1941 crops were soybeans and corn, respectively. No fertilizer was added to the soybeans and the corn was fertilized only lightly, the exact quantity being indeterminable. At location FWR, small grain fertilized with nitrate of soda preceded the peanuts. At location ZRW, cotton was grown in 1942 and fertilized with 600 pounds of a 6–8–4. In 1941, corn was grown and to it was added the equivalent of 30 pounds per acre both of P_2O_5 and K_2O. In 1940, the corn crop received only 200 pounds of ammonium sulfate. In the field at location RD, crotalaria was plowed under both in 1942 and 1941. In 1940, barley, also plowed under, received 700 pounds of a 5–7–5. In the previous year, 100 pounds K_2O per acre were added to this soil on which a peach orchard was then located.

by the procedure already described and the data are presented in Table 6 and Fig. 4.

Two features of the data deserve special comment. First, the application of potash in the presence of gypsum did not affect fruit quality. This is evidenced by comparison of the data from the gypsum-potash plots with data from the plots receiving only gypsum. Second, on the three soils of lowest levels of exchangeable potassium, the addition of potash has resulted in yield increases, but only after the calcium requirement of the fruit was met. The limestone treatment, as shown elsewhere, did not supply sufficient calcium for normal kernel development and for that reason the limestone-potash treatment cannot be used to determine potash response.

Although the response obtained from potassium is greatly dependent on the supply of calcium, the addition of potash was not found to increase yields at locations RD (Fig. 4) or CLB (Table 4) even when gypsum was added. The potassium levels of these soils would be considered low for most other crops. From the responses obtained

TABLE 6.—*Effect of potash on quality of Virginia Bunch peanuts at four locations 1943.**

Potash treatment†	Total cavities		True shelling %	Soil analysis
	No. examined	% filled		
		Norfolk Loamy Sand (RPF)		
None........	3,092	51.8	60.2	pH =4.7
45 lbs. K_2O	3,316	46.1	55.5	Ex. cap. =2.34
				Ex. Ca =.21
L.S.D. (.05)		6.74	8.35	Ex. Mg =.17
				Ex. K =.04
		Norfolk Sand (FWR)		
None	1,888	42.2	48.6	pH =4.6
45 lbs. K_2O	2,012	39.0	49.7	Ex. cap. =1.98
				Ex. Ca = .54
L.S.D. (.05)		9.12	8.15	Ex. Mg = .21
				Ex. K = .04
		Ruston Sandy Loam, Deep Phase (ZRW)		
None	1,959	41.0	55.4	pH =5.1
45 lbs. K_2O	1,878	38.9	51.6	Ex. cap. =2.78
				Ex. Ca = .54
L.S.D. (.05)		8.45	7.94	Ex. Mg = .25
				Ex. K = .04
		Runston Sand (RD)		
None	1,596	45.1	45.6	pH =5.6
45 lbs. K_2O	1,660	52.5	49.7	Ex. cap. =4.06
				Ex. Ca =1.15
L.S.D. (.05)		12.96	4.00	Ex. Mg = .40
				Ex. K = .12

*Four replications for RPF, FWR, and RD; three for ZRW.
†Base treatment of 400 pounds of gypsum.

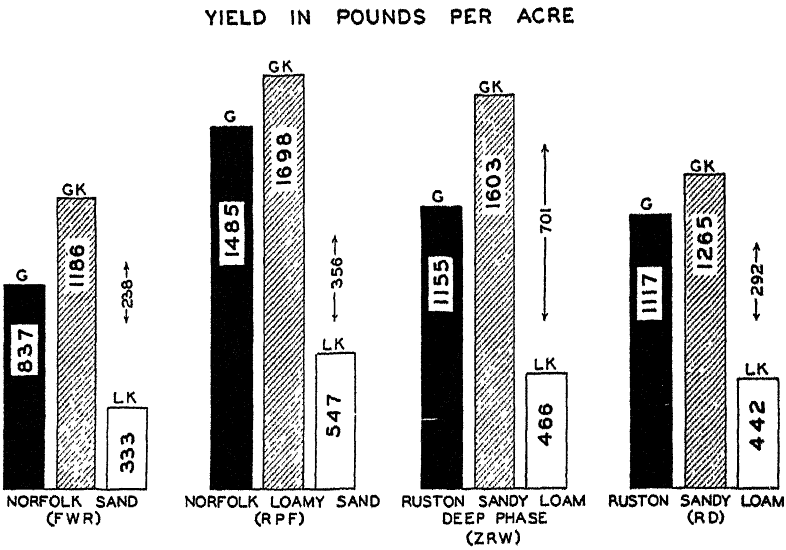

FIG. 4.—The effect of treatment on the yield of Virginia Bunch peanuts at four locations. Least significant difference (.05) values indicated by arrows.

on the three soils lowest in potassium, it would seem that at least two conditions are necessary before potassium could be expected to increase yields of peanuts, *viz.*, (a) an ample supply of calcium, and (b) a very low level of soil potassium.

A pronounced vegetative response from added potash was observed at all four locations. When this is considered together with the fact that yield increases were obtained without corresponding increases in quality, it would appear that the effect of potassium is one primarily associated with plant size rather than with kernel development, as in the case of calcium.

OIL CONTENT AS INFLUENCED BY POTASSIUM, MAGNESIUM, AND CALCIUM

It is known that plump kernels contain a higher percentage of oil than those that are shrivelled. In determining the effects of mineral elements on oil content, it is therefore necessary to make comparisons on kernels of uniform plumpness. In this study, large and medium kernels were selected from certain plots fertilized differently with potassium, magnesium, and calcium. They were examined closely and separated into two groups, *viz.*, (a) those that were very plump, and (b) the remainder which were made up of kernels with somewhat wrinkled seed coats. They were analyzed for oil and the results are presented in Table 7.

It will be noted that the oil content of the plump kernels was virtually unaffected by treatment, although the yields resulting from the particular treatments selected for study varied from 154 to 1,028 pounds per acre. The oil content of the "remainder" of the

large and medium kernels from the gypsum-treated plots, however, is higher than it is in those from any other treatment. This is probably due to the fact that the gypsum "remainder" kernels were less wrinkled than the corresponding kernels from the other treatments. Even though this is true, the range in percentage oil is quite small.

In view of these data which show that even under widely different conditions of nutrient supply the percentage oil in well-developed kernels is quite constant, it would seem that the effect of fertilization on oil content is one associated primarily with good kernel development.

TABLE 7.—*Effect of potassium, magnesium, and calcium on the oil content of large and medium size kernels of two degrees of plumpness of the Virginia Bunch variety (MLW).**

Treatment†	Large and medium kernels		Corrected yield, lbs. per acre
	Plump, % oil	Remainder, % oil	
Check	49.8	48.1	419
K_2SO_4	49.8	47.7	154
$MgSO_4 \cdot H_2O$	50.0	48.5	283
$CaSO_4 2 \cdot H_2O$	50.3	49.6	1,028
L.S.D. (.05)	None	1.4	271
(.01)	None	2.0	365

*Four replications.
†Treatments were made in the row at planting time (3 to 5 inches below seed level) and again to the fruiting medium at early bloom. At each time the following rates of materials were used: (a) K_2SO_4 to supply 48 pounds K_2O per acre; (b) $MgSO_4 \cdot H_2O$ to supply 15 pounds MgO per acre; and (c) $CaSO_4 \cdot 2H_2O$ to supply 130 pounds CaO per acre.

SUMMARY AND CONCLUSIONS

Field experiments in which applications of potash were made to large-seeded type peanuts were initiated on soils of widely different chemical characteristics. A study was made of the effects of potassium when placed in either or both of two zones of plant development (rooting and fruiting zones) with and without calcium or magnesium.

Through the use of a rather detailed system of fruit classification, it was found that potassium did not aid in the filling of fruit and that under certain conditions it lowered the true shelling percentage and percentage of ovarian cavities filled. For example, when compared with no treatment, potassium placed in the rooting medium tended to inhibit kernel development whenever the fruiting medium received potassium or was left untreated.

When potassium was used in the fruiting medium, it lowered both quality and yield whenever the accompanying rooting medium treatment supplied either potassium or magnesium. The effect of potassium in the fruiting medium was less pronounced whenever the rooting medium received calcium or was left untreated. When potassium was applied to the fruiting zone and used in combination with calcium applied in the same area, it had no unfavorable effect on quality.

The necessity of meeting the calcium requirement of the peanut fruit before the true effects of added potash on yield can be measured, was emphasized. Even when the calcium supply was adequate for normal fruit development, however, yields were not increased by the use of potassium on soils which would ordinarily be considered low in this element for most other crops. On soils of extremely low potash level, however, the use of potash brought about a marked vegetative response and a significant increase in yield. Thus, it is concluded that increased yields from the use of potash may be expected when (a) there is an adequate supply of calcium to bring about good filling of fruit, and (b) when the level of soil potassium is extremely low.

Data are presented to show that potassium affects yield through its influence on plant size rather than on kernel development.

In general, the use of magnesium had an unfavorable effect upon kernel development particularly when placed in the rooting zone in combination with potassium supplied to the fruiting medium. The favorable effect of calcium upon fruit development was not affected by the addition of potassium or magnesium to the rooting medium.

The percentage of oil in plump kernels of the large and medium size was not affected by the potassium, magnesium, or calcium treatments. Although the oil content of the slightly wrinkled kernels in this size group was highest in those from plots which had received added calcium, the difference was small. The direct effects of these mineral elements upon the oil composition of well-developed kernels was of little consequence.

LITERATURE CITED

1. BURKHART, LELAND, and COLLINS, E. R. Mineral nutrients in peanut plant growth. Soil Sci. Amer. Proc., 6:272–280. 1942.
2. COLLINS, E. R., and MORRIS, H. D. Soil fertility studies with peanuts. N. C. Agr. Exp. Sta. Bul. 330. 1941.
3. COLWELL, W. E., and BRADY, N. C. The effect of calcium on yield and quality of large-seeded type peanuts. Jour. Amer. Soc. Agron., 37:000–000. 1945.
4. REED, J. FIELDING. Soil tests indicate potash levels. Better Crops With Plant Food. March, 1944.
5. WEST, H. O. Peanut production. Miss. Agr. Exp. Sta. Bul. 366. 1942.

THE BEHAVIOR OF FOUR VARIETIES OF PEANUTS AS AFFECTED BY CALCIUM AND POTASSIUM VARIABLES[1]

G. K. MIDDLETON, W. E. COLWELL, N. C. BRADY, AND E. F. SCHULTZ, JR.[2]

THE present investigation was undertaken to determine the relative response of four varieties of peanuts, differing widely in seed size, to additions of calcium and potassium on soils low in these elements. The response of the large-seeded Virginia type peanuts to additions of these elements has been reported (1, 3)[3] and calcium was found to be of great importance in proper kernel development. In fact, the Virginia Bunch variety was so dependent upon calcium supply that almost complete fruit failure resulted on soils low in this element when supplementary calcium was not added. Increased yields resulted from the use of potassium only where the soil potassium level was very low and the calcium requirements of the fruits were met.

Although similar investigations using small-seeded varieties have not been made under widely differing soil conditions, there was reason to believe that these varieties might have a somewhat lower calcium requirement. Yields of Spanish varieties, which are small-seeded types grown widely in the southeastern states, have been found to be affected only slightly by the use of calcium (4, 9).

In preliminary investigations in North Carolina, the relative response of the small- and large-seeded varieties to added calcium was found to depend on the soil calcium level. Thus, on soils of relatively high calcium content, there was no response of either of the types to calcium additions (8). However, somewhat different responses were observed on soils low in calcium where this element might be expected to be more nearly limiting (2). Under these conditions proper fruit development of the large-seeded variety was limited by the low calcium supply. A small-seeded variety did not require additional calcium for normal fruit development.

These experiments were of a preliminary nature and did not provide a suitable number of comparisons to determine with certainty the relative calcium requirements of the large- and small-seeded types. The need for further study on the problem is recognized when consideration is given to the importance that varietal differences in nutrient requirements would have on both peanut breeding and soil fertility programs.

The soils selected for the present studies were low in both calcium and potassium and were of lower fertility levels than those commonly

---

[1]Contribution from the Department of Agronomy, North Carolina Agricultural Experiment Station, Raleigh, N. C. Published with the approval of the Director as Paper No. 204 of the Journal Series. Received for publication January 29, 1945.

[2]Associate Agronomist (in charge, peanut breeding investigations), Associate Agronomist (in charge, peanut soil fertility investigations), and Assistants in Agronomy, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 457.

cropped to peanuts in the main peanut-producing area of North Carolina. However, they are considered representative of soils in the southern Coastal Plain area of the state.

One objective of conducting the experiments on low fertility soils of this area was to obtain information which would be of immediate practical value to inexperienced growers. A second objective was that of obtaining information on the basic principles governing the behavior of the four varieties to calcium and potassium variables. The principles would be expected to apply under other conditions, even though the responses might be manifested to a greater or lesser degree than those herein reported.

Particular attention was given in this study to the effects of two calcic materials and of potash upon varietal behavior as measured by (a) yield, (b) true shelling percentage, (c) percentage ovarian cavities[4] filled, and (d) pounds of oil per acre.

MATERIALS AND METHODS

VARIETIES USED

The four varieties used in this study were selected to represent both the large-seeded types commonly grown in the main peanut area of Virginia and North Carolina and the smaller seeded varieties produced in the states further south. A photograph showing the appearance of fruit of each of the varieties is presented in Fig. 1.

Virginia Bunch is a large-seeded type peanut with an erect growth habit. The strain used was North Carolina 31, which has not been found to differ materially from other strains of Virginia Bunch.

North Carolina Runner is of smaller seed size than the Virginia Bunch and has a prostrate growth habit. Insofar as the authors know, this variety is the same as that grown widely in the southeastern states and has often been referred to as the Florida Runner or Georgia Runner. It is a later maturing variety than Virginia Bunch and is commonly used for "hogging-off" purposes.

Spanish 2B is a relatively large-seeded strain of the Spanish type. It has an erect growth habit and matures earlier than Virginia Bunch but not so early as White Spanish.

White Spanish is the common small-seeded type peanut produced widely in the southern states for the oil trade as well as for edible purposes.

CALCIUM AND POTASSIUM TREATMENTS

The following variables with respect to calcium and potassium were used: (a) No treatment, (b) gypsum, (c) gypsum plus potash, and (d) limestone plus potash. Gypsum was applied on the foliage at early bloom at the rate of 400 pounds per acre. Muriate of potash to supply 45 pounds of K_2O per acre was added at the time of emergence. Limestone (dolomitic) was added in the row at the time of planting at the rate of 400 pounds per acre.

CULTURAL PRACTICES

Shelled seed were planted by hand in 30-inch rows. Two seeds were dropped every 8 inches in the case of Virginia Bunch and North Carolina Runner and every 6 inches for Spanish 2B and White Spanish. Six rows 30 feet long constituted a single plot which was approximately 0.01 acre in size. The experimental design used was a 4 × 4 simple lattice.[5]

---

[4]A peanut fruit has one or more compartments, in each of which one kernel may form. An individual compartment is referred to as an ovarian cavity.

[5]The authors wish to acknowledge the assistance of J. A. Rigney, Associate in Experimental Statistics, in preparing the experimental designs used and in supervising the statistical analyses.

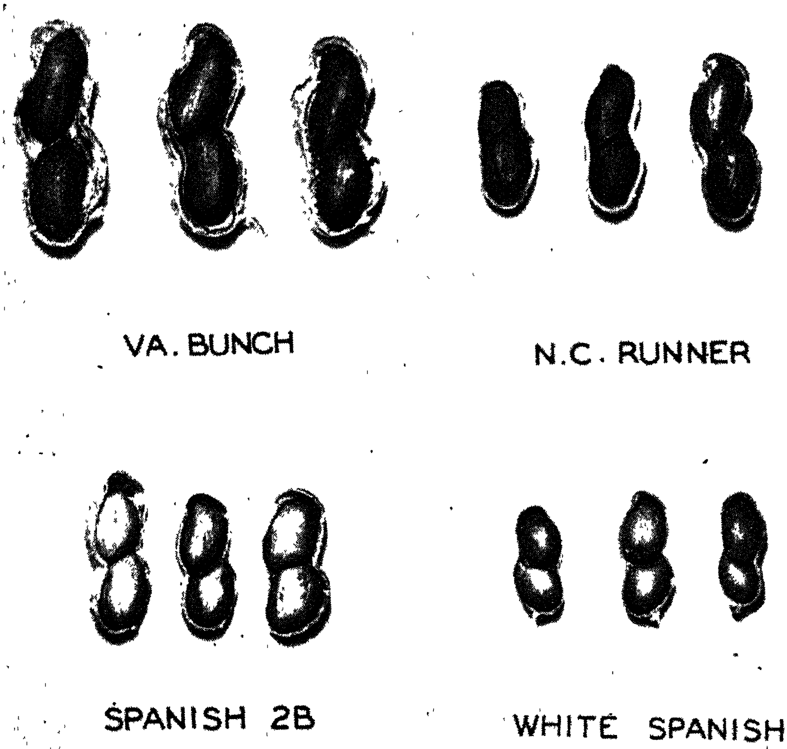

FIG. 1.—Specimens of seed of the varieties used in the experiments.

Regular cultivation practices were followed, and all plants were dusted three times with sulfur, the rate of each application being 15 pounds per acre. Differences in time of maturity of the varieties were taken into consideration in determining digging dates, which are given with those of other operations in Table 1.

ANALYTICAL METHODS[6]

Exchange properties of soils were determined by ammonium acetate extraction and are expressed as M.E. per 100 grams of soil. Phosphorus was extracted by 0.002N H_2SO_4 and organic matter was determined by dry oxidation. The data are average values from four samples, each of which consisted of 20 portions of soil from the plow layer of unfertilized plots.

Oil determinations were made on kernels separated by the screening procedure described in detail under "Measurement of Yield." The kernels were ground to pass through a 20-mesh sieve and extracted with petroleum ether for a period of 22 to 24 hours. All results are expressed on the oven-dry basis.

DESCRIPTION OF EXPERIMENTAL FIELDS

The experimental fields were all located in the southern coastal plain area of the state within 35 miles of Raeford, N. C.

[6]Analyses made under the supervision of J. R. Piland, Associate Soil Chemist.

Pertinent analytical data on surface soils are shown in Table 2. It will be noted that three of the soils selected were very low in exchangeable calcium and potassium and that the fourth (RD)[7] was only moderately high in these elements. Also, the organic matter content of the soil at location RD was the highest of any of the soils used.

TABLE 1.—*Dates of carrying out certain operations at each of four experiments.*

Operation	Location*			
	RPF	FWR	ZRW	RD
Soil samples taken	Apr. 22	Apr. 23	Apr. 21	Apr. 20
Planted	Apr. 22	Apr. 23	Apr. 21	Apr. 20
Potash applied	May 11	May 11	May 11	May 10
Gypsum applied	June 22	July 2	June 22	June 17
White Spanish dug	Sept. 1	Sept. 3	Sept. 2	Sept. 13
Spanish 2B dug	Sept. 1	Sept. 3	Sept. 21	Sept. 13
Virginia Bunch dug	Sept. 15	Sept. 23	Sept. 23	Oct. 4
N. C. Runner dug	Sept. 15	Sept. 23	Sept. 23	Oct. 4
All varieties picked	Oct. 20	Oct. 22	Oct. 20	Nov. 1

*Initials are for cooperating growers.

TABLE 2.—*Certain chemical characteristics of surface soil and soil types at each of the four locations.*

Location and soil type	pH	B. E. cap.; M. E./100 grams	Ex. Ca, M. E./100 grams	% Ca sat.	Ex. Mg, M. E./100 grams	Ex. K, M. E./100 grams	O. M. %	P, p.p.m.
(RPF) Norfolk loamy sand	4.7	2.34	0.21	9	0.17	0.04	0.9	34
(FWR) Norfolk sand	4.6	1.98	0.54	27	0.21	0.04	1.0	29
(ZRW) Ruston sandy loam, deep phase	5.1	2.78	0.54	17	0.25	0.04	1.4	40
(RD) Ruston sand	5.6	4.06	1.15	28	0.40	0.12	3.0	86

Previous cropping and fertilization histories of the fields are reflected to some degree by the chemical analyses. For example, at location RD where potassium and organic matter were relatively high, crotalaria had been plowed under in 1941 and again in 1942. In 1940, barley, also plowed under, received 700 pounds of a 5–7–5 fertilizer. In 1939, 100 pounds of K_2O per acre were applied to this soil on which peach trees were then growing.

The fields at locations RPF and FWR had not been fertilized the previous year and had received only light fertilization the years before. Cover crops had not been grown recently at either of these locations. At location ZRW the general level of fertility was somewhat higher. Cotton grown in 1942 was fertilized with the equivalent of 600 pounds of 6–8–4. Corn in the two previous years received a total of 40, 30, and 30 pounds per acre N, P_2O_5, and K_2O, respectively.

MEASUREMENTS OF YIELDS

To obtain yield data the peanuts were stacked and, after curing in the field, were threshed with a commercial picker. As a means of adjusting field weights to values of a uniform shelling percentage, samples of 500 to 1,000 grams were taken from each plot, weighed, cleaned, then shelled by means of an electrically

[7]Initials of cooperating growers are used to designate experimental fields.

powered sheller. In accordance with the size specifications set up by the U. S. Agricultural Marketing Service for grading Spanish, Runner, and Virginia type peanuts (5, 6, 7), the kernels were passed over a screen with oblong perforations $\frac{15}{64}$ inch in width. This procedure made possible the separation of the plump kernels from the remainder of the sample regardless of the variety used, and thus a uniform basis of comparison was provided. The proportion of the original sample remaining on top of the screen (plus the plump kernels passing through) was expressed as a percentage of the total sample. This "correction factor" was used as a means of adjusting field weights to values of a common shelling percentage of 60, as shown in the following formula:

Corrected yield (lbs. per acre) =

$$\frac{\text{Field weight (lbs. per acre)} \times \text{Correction factor (\%)}}{60}.$$

EVALUATION OF FRUIT QUALITY

To obtain greater accuracy and precision in measuring fruit quality than are provided by the ordinary technics, a rather detailed classification of fruit was made on the basis of kernel development. The procedure, described in detail elsewhere (3), consisted briefly of the following steps. At digging time the fruit from 10 to 20 plants were detached, dried, and taken to the laboratory. After the sample was freed from all trash, each fruit was examined and classified in such a manner that it was possible to determine in a given sample the total number of ovarian cavities and to calculate the percentage of the total which contained well-developed kernels. The data herein reported are based on a total of 48,138 ovarian cavities.

Separation of "large and medium" kernels was made as described above. Their weight was used in determining true shelling percentage as shown by the following formula:

$$\text{True shelling percentage} = \frac{\text{Weight of large and medium kernels} \times 100}{\text{Weight of fruit in cleaned sample}}.$$

This value is more precise than the correction factor described above. The true shelling percentage more nearly reflects the exact conditions prevailing in the field since in its determination the empty shells are considered, none having been blown through a thresher. Furthermore, unlike the correction factor, it is based on a trash-free sample. As pointed out previously, the correction factor is simply a means of adjusting field weights to common shelling percentage.

RESULTS AND DISCUSSION

When the results of yield together with those of true shelling percentage and percentage ovarian cavities filled are considered for the four varieties at four separate locations, it is apparent that their presentation involved the tabulation of considerable data. Averages of data from all experiments cannot be used without considerable sacrifice of pertinent information from individual experiments. Furthermore, the yield and quality data of any particular experiment are related to such an extent that their separation seems inadvisable. In an attempt to bring out more specifically the effects of treatment upon both yield and quality, the results from the individual experiments are presented separately in Figs. 2 and 3, and in Table 3.

EFFECTS OF TREATMENTS ON YIELD AND QUALITY OF EACH VARIETY

Virginia Bunch.—The most striking feature of the data for the Virginia Bunch variety is the pronounced response obtained from gypsum at all locations. At location RD, where the calcium content

of the soil is relatively high, the response to calcium additions was least marked. The largest increase in yield brought about by gypsum was 1,214 pounds per acre at location RPF.

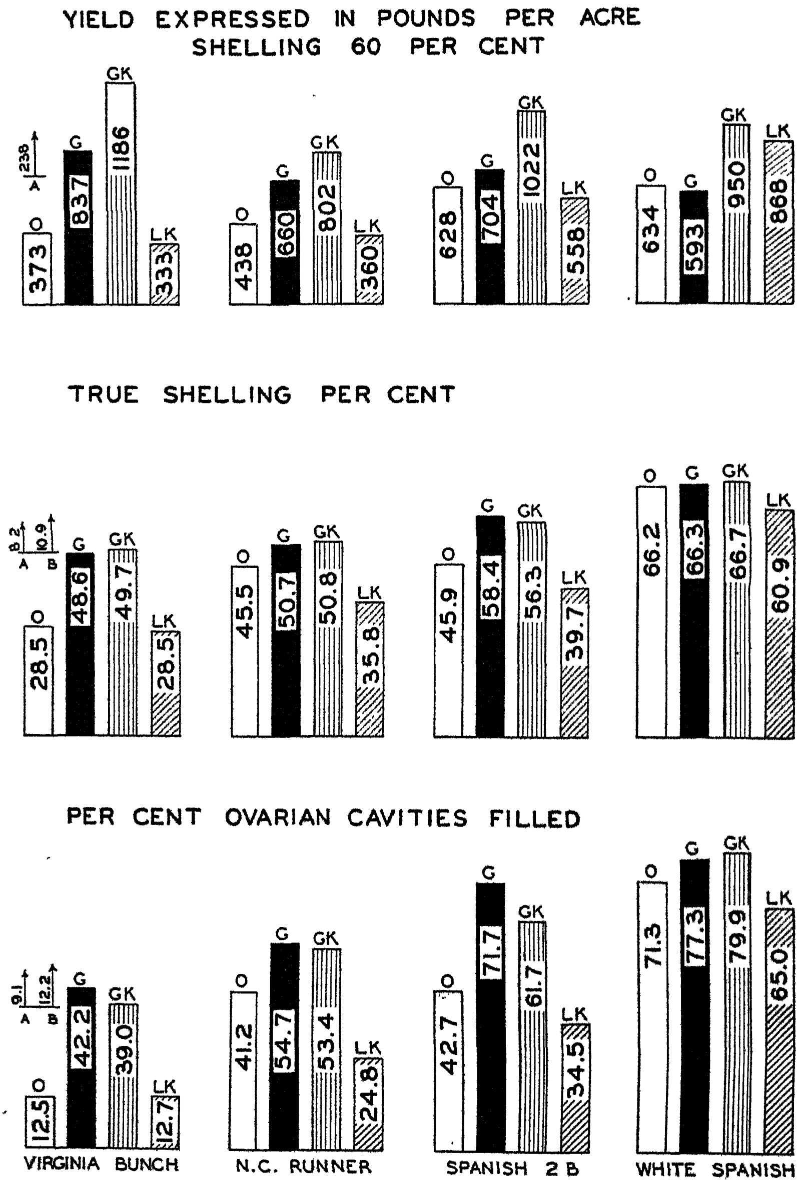

FIG. 2.—The effect of certain soil treatments on yield and quality of four varieties of peanuts grown on a Norfolk loamy sand in 1943 (RPF). A = Least significant difference at 5% level; B = Least significant difference at 1% level.

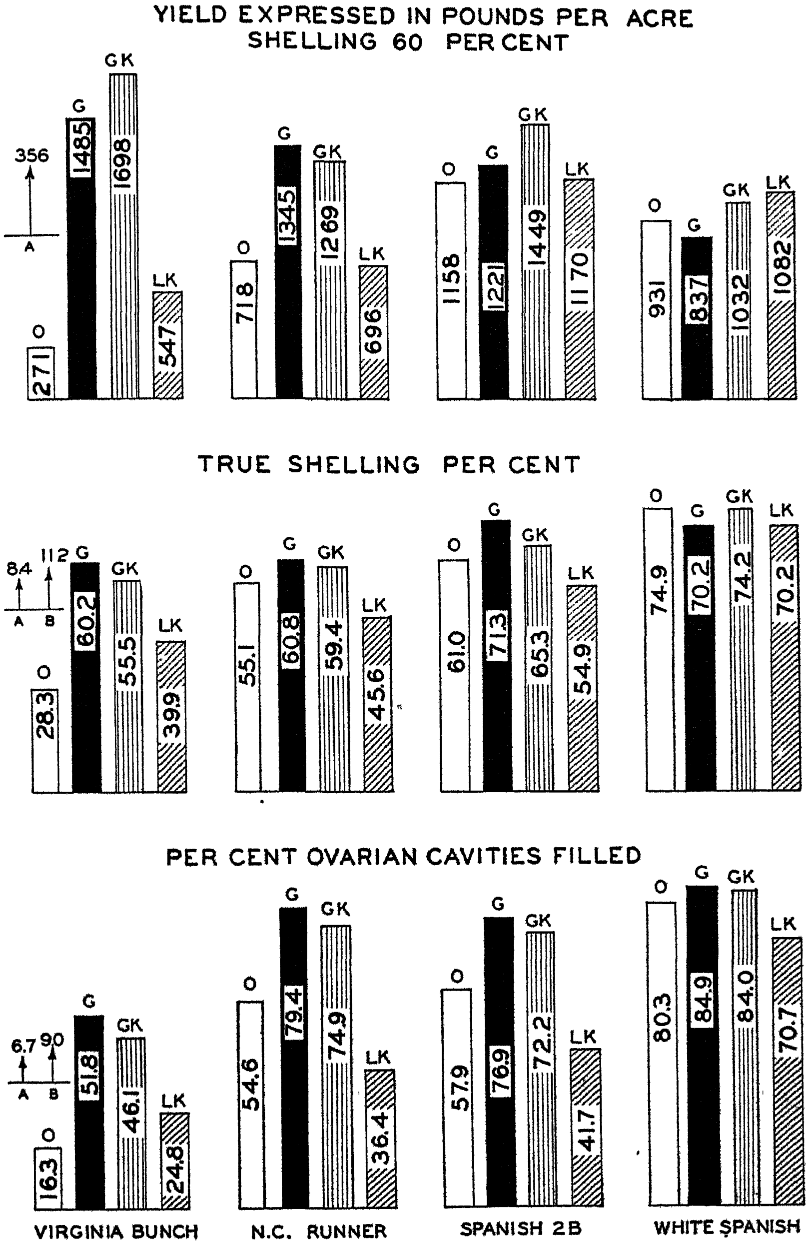

FIG. 3.—The effect of certain soil treatments on yield and quality of four varieties of peanuts grown on a Norfolk sand in 1943 (FWR). A = Least significant difference at 5% level; B = Least significant difference at 1% level.

Limestone placed in the row did not meet the calcium requirement of the fruit as did gypsum applied to the foliage. Although yield and quality were increased slightly by the limestone-potash treatment at two of the locations, on soils of low calcium levels the limestone treatment was entirely unsatisfactory for Virginia Bunch.

A comparison of the yield data from the gypsum and the gypsum-potash plots shows that the response to added potash is small relative to that previously noted from the addition of gypsum. This is particularly significant since the levels of soil potassium were very low, 0.04 M. E. per 100 grams at three locations, and since there was a pronounced vegetative response from potash on these three soils.

TABLE 3.—*Yield and quality of four varieties of peanuts as affected by soil treatments at two locations.*

Treatment	Ruston sandy loam, deep phase (ZRW)				Ruston sand (RD)			
	Va. Bunch	N. C. Runner	Spanish 2B	White Spanish	Va. Bunch	N. C. Runner	Spanish 2B	White Spanish
	Yield in Pounds per Acre, Shelling 60%							
Check	251	737	1,614	1,164	842	911	1,208	1,463
Gypsum	1,155	1,514	2,051	1,059	1,117	1,143	1,747	1,888
Gypsum+potash	1,603	1,949	2,504	1,283	1,265	1,104	1,527	1,566
Limestone+potash	466	742	1,296	1,318	442	1,081	1,189	1,581
L.S.D. (.05)	701				292			
	True Shelling Percentage							
Check	20.9	41.2	55.7	66.4	31.9	36.1	51.8	72.4
Gypsum	55.4	57.3	60.5	65.2	45.6	47.0	59.9	72.7
Gypsum+potash	51.6	56.8	62.0	69.6	49.7	43.6	58.7	72.8
Limestone+potash	35.6	45.2	53.9	67.9	24.3	36.5	52.8	72.3
L.S.D.	(.05) = 7.9; (.01) = 10.7				(.05) = 4.0; (.01) = 5.3			
	Percentage Ovarian Cavities Filled							
Check	10.8	39.1	51.0	74.2	33.8	54.8	58.7	82.4
Gypsum	41.0	69.2	68.8	79.9	45.1	59.6	69.4	84.2
Gypsum+potash	38.9	64.4	68.5	77.6	52.5	56.4	67.2	83.8
Limestone+potash	19.4	37.0	51.5	72.1	14.6	47.6	55.6	81.3
L.S.D.	(.05) = 8.5; (.01) = 11.4				(.05) = 13.0; (.01) = 17.3			

The effect of added potash on kernel development, discussed elsewhere in detail (1), deserves special note. It will be observed that, in these experiments, potash has not aided in filling of fruit. In fact, it tended to lower shelling percentage and the percentage ovarian cavities filled. Thus were it not for the vegetative response from added potassium noted above, it is likely that an actual lower-

ing of yields may have resulted from additions of this element. It is evident, therefore, that the beneficial effect of potash was one associated with an increase in plant size, rather than with kernel development as in the case of calcium.

North Carolina Runner.—From the standpoint of both kernel development and yield, the response of the North Carolina Runner variety to added gypsum is similar to that of Virginia Bunch but of a considerably lowered magnitude. For example, where the check yields of Virginia Bunch and North Carolina Runner were 271 and 718 pounds per acre, respectively, the increases from added gypsum were 1,214 and 627 pounds per acre (RPF), respectively. The true shelling percentage values of the peanuts from untreated plots were 28.3 for Virginia Bunch and 55.1 for North Carolina Runner, whereas the corresponding values from the gypsum-treated plots were essentially the same, *viz.*, 60.2 and 60.8, respectively. Although the calcium requirement of the North Carolina Runner was found to be somewhat lower than that of the Virginia Bunch, maximum yields of the former variety were not obtained without added calcium.

It will be noted, as in the case of Virginia Bunch, that the limestone-potash treatment produced fruit of poor quality. In comparison with no treatment, the quality was significantly lowered at location RPF and FWR by the use of this treatment combination.

Potash affected the yield of this variety less than it did that of Virginia Bunch. Although a response in vegetative growth occurred on the three soils lowest in potassium, yields were not significantly increased in any of the experiments. As with Virginia Bunch, potash additions tended to lower fruit quality.

Spanish 2B.—The calcium requirement of Spanish 2B was found to be lower than that of either Virginia Bunch or North Carolina Runner. Without exception, however, the quality was significantly improved by the use of gypsum. The effect of calcium on fruit quality was somewhat greater than it was on yield. As with Virginia Bunch and North Carolina Runner, the use of limestone in the row did not meet the calcium requirement for normal fruit development. This is evidenced by comparing data on yield, true shelling percentage, or the percentage of the ovarian cavities filled from the gypsum-potash plots with the corresponding data from the plots receiving limestone and potash.

Potash exerted essentially the same effect on vegetative growth and on both yield and quality of fruit of Spanish 2B as it did on Virginia Bunch.

White Spanish.—Even on the soil of the lowest calcium level, neither yield nor quality of White Spanish peanuts was affected by the addition of gypsum.[8] This behavior is in marked contrast to

[8]Data from location RD where soil calcium was highest (1.15 M.E. per 100 grams) show that gypsum significantly increased the yields. These data are not in line with those obtained from the other experiments nor with data on true shelling percentage and percentage cavities filled from the same plots of this experiment. Furthermore, a consideration of the data on soil calcium would lead one to expect a smaller response on this soil from the use of gypsum than on the other three where no yield response occurred. Therefore, little confidence is being placed in this apparent response.

that of the other varieties, and the data illustrate the extremely low calcium level at which normal kernel development of this variety may take place.

Potash exerted essentially the same effect on the yield of the White Spanish variety as it did on Spanish 2B or Virginia Bunch. At one location (FWR), the use of potash resulted in an increase in yield which was highly significant; and at two locations (RPF and ZRW), the differences were somewhat below those required for significance at the .05 level. A comparison of quality of fruit from the gypsum plots with that from gypsum-potash plots shows that potash had no effect on fruit quality. In comparison with the gypsum-potash treatment, the limestone-potash treatment resulted in fruit of slightly lower quality at the three locations where soil calcium was lowest. This was especially true for percentage cavities filled in which case the depression was highly significant at locations RPF and FRW.

COMPARATIVE RESPONSE OF THE FOUR VARIETIES TO EACH FERTILIZER TREATMENT

In making comparisons between varieties it must be kept in mind that all yields have been adjusted to a common shelling percentage of 60. Therefore, the values showing the yields of Spanish varieties are higher than would ordinarily be reported since the yields of these varieties are commonly expressed in terms of a shelling percentage of 70.

It is readily seen from the data presented that the relative behavior of the four varieties greatly depends upon the soil treatment. For example, without treatment, Virginia Bunch yielded lowest at all locations and the Spanish varieties yielded highest.

However, when all varieties received gypsum, the yields of Virginia Bunch were highest at two locations and compared favorably with those of the Spanish varieties at the other two. The fact that the use of gypsum on these soils low in calcium has been relatively more beneficial to Virginia Bunch is in agreement with the differences in the calcium requirements of the varieties as already discussed.

The response to added potash was similar for all varieties and, therefore, the relative yields obtained from the gypsum-potash treatment were essentially the same as those obtained from the use of gypsum alone.

With the limestone-potash treatment, the Spanish varieties yielded higher than Virginia Bunch or North Carolina Runner. This behavior is in agreement with the lower calcium requirements of the Spanish varieties and the inadequacy of the limestone treatment as a means of supplying available calcium necessary for fruit development.

When all comparisons are considered, it is evident that on soils low in calcium the production of Virginia Bunch peanuts is more hazardous than that of Spanish varieties.

The results call attention to the need for consideration of soil characteristics and fertilization practices in conducting variety experiments with peanuts. Likewise, they emphasize the necessity for considering the nutritional requirements of peanuts on the basis of variety.

COMBINATION OF VARIETY AND FERTILIZATION FOR HIGHEST YIELDS

From the standpoint of peanut production only the highest yielding combinations are of practical interest. The highest yielding combinations differed from experiment to experiment but, in general, Virginia Bunch or Spanish 2B fertilized with gypsum and potash were found to be superior.

From one location to another, the effects of the fertilization treatments on a particular variety are more consistent than the relative yields of the four varieties receiving a given treatment. This suggests that even when the calcium and potassium requirements are met some factor not herein investigated influences the yield of one variety more than it does another. In this connection, it is of interest to note that the Spanish varieties performed relatively better on the soils of highest organic matter levels. The possibility of a differential response from nitrogen is suggested and this problem is now under investigation.

OIL CONTENT

Oil determinations were made on kernels separated in the manner described under "Materials and Methods". The results obtained are presented in Fig. 4 and Table 4.

Perhaps the most significant feature of these data is the remarkably small differences in oil contents of the plump kernels of the four varieties from plots on which wide differences in yield and quality were obtained. However, there are some significant differences in oil content brought about by treatment even though the magnitude of these differences is not large. For the three varieties which responded to additions of gypsum (Virginia Bunch, North Carolina Runner, and Spanish 2B), the oil is highest in the kernels from fruit of a high shelling percentage. This is true rather consistently on the three soils of lowest calcium content.

A probable explanation of the effect of treatment may be made on the basis of supplementary data showing that oil content is affected more by plumpness than by mineral nutrient supply.

In an experiment with the Virginia Bunch variety (MLW) which

TABLE 4.—*Percentage oil content of "large and medium kernels" of four varieties of peanuts as affected by soil treatment at two locations.*

Treatment	Location ZRW				Location RD			
	Va. Bunch	N. C. Runner	Spanish 2B	White Spanish	Va. Bunch	N. C. Runner	Spanish 2B	White Spanish
Check	48.9	49.7	49.7	51.8	48.1	48.5	50.5	51.7
Gypsum	49.3	49.6	51.2	53.7	49.3	49.2	50.3	51.2
Gypsum+potash	50.1	51.2	51.0	55.1	47.8	48.4	50.5	51.6
Limestone+potash	46.9	50.0	49.8	51.3	47.3	48.0	49.4	49.9
L.S.D.	(.05) = 2.1; (.01) = 2.8				(.05) = 1.6; (.01) = 2.2			

is described in detail elsewhere (1), yields varying from 154 to 1,028 pounds per acre were obtained by the additions of the sulfates of calcium, potassium, and magnesium. Kernels from each plot remaining on top of a screen with 15/64 × 1 inch perforations were examined closely and separated into two groups, *viz.*, (a) those very plump,

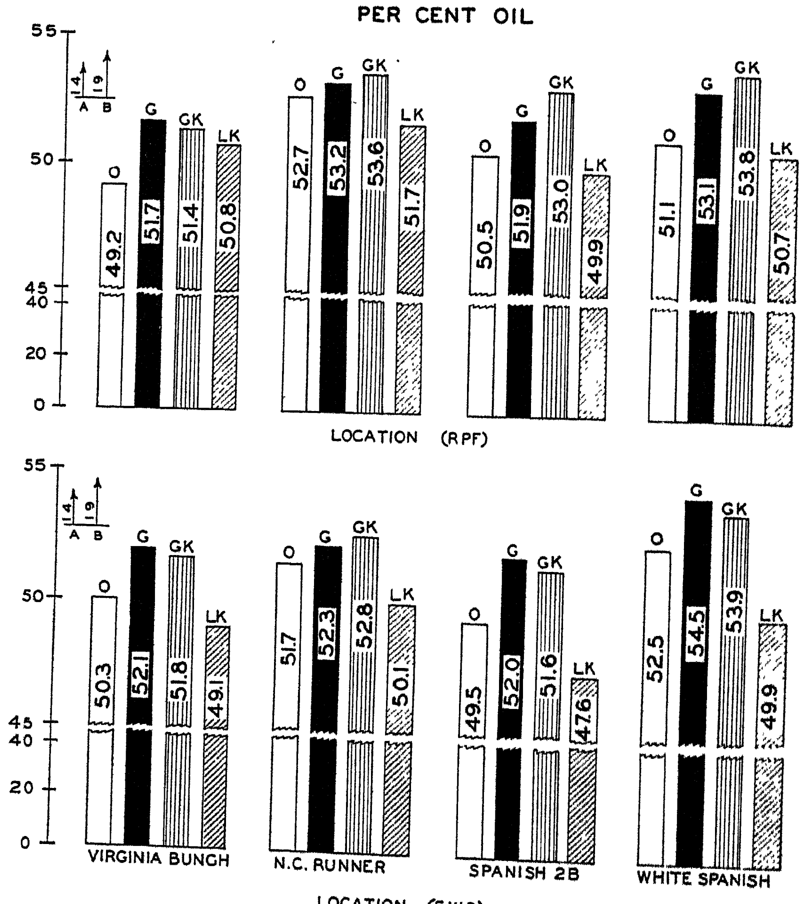

FIG. 4.—The effect of certain soil treatments on oil content of kernels of four varieties of peanuts at two locations. A = Least significant difference at 5% level; B = Least significant difference at 1% level.

and (b) the remainder, which consisted of kernels with somewhat wrinkled seedcoats. It was found that the percentage oil in the plump kernels was virtually unaffected by treatment. However, the oil content of the "remainder" of the large and medium kernels was highest in the kernels from the gypsum-treated plots.

The fact that the oil content varies with kernel size of each of the four varieties is shown by data in Table 5. Without exception, the

larger kernels of a given variety were higher in oil than the smaller ones. The differences are particularly pronounced with Virginia Bunch and least so with White Spanish.

In view of these results it appears logical to assume that the variations in oil content shown by data in Fig. 4 and Table 4 are due primarily to variations in degrees of plumpness and not to the specific influence of mineral nutrition on kernel composition. If this is true, the effect of gypsum on White Spanish is an especially interesting one. The oil content of kernels of this variety from the three soils lowest in calcium is raised by the application of gypsum even though this treatment had no effect on yield or true shelling percentage and only a slight effect on percentage of the ovarian cavities filled. Thus it would seem that the oil content, a criterion very sensitive to plumpness, has shown an effect of gypsum on White Spanish kernel development which was undetected by either yield or quality measurements.

YIELD OF OIL PER ACRE

From the oil content data already presented, it is obvious that the yield of oil per acre is quite closely related to the yield of plump kernels. Individual oil yields are not presented, but they can be readily obtained by multiplying the percentage of oil by the corresponding yield of kernels (60% of the fruit yield herein reported). The yields of oil by treatment and variety have been averaged for all locations and the data are presented in Table 6. The interpretation of these average values is, of course, subject to certain limitations because variations associated with locations are not brought out.

TABLE 5.—*Percentage of oil as affected by kernel size (CLB).*

Variety	Large*	Medium†	Remainder
Virginia Bunch	52.5	46.4	36.4
N. C. Runner	54.0	51.1	40.1
Spanish 2B	54.0	51.0	39.6
White Spanish	54.5	54.7	46.8

*Remaining on top of a screen with 20/64 inch perforations.
†Passing through a screen of 20/64 inch perforation but staying on top of a 15/64 inch screen.

TABLE 6.—*Pounds of oil per acre, average yields from four locations.*

Variety	Treatment			
	Check	Gypsum	Gypsum + potash	Limestone + potash
Virginia Bunch	127	350	435	133
N. C. Runner	212	355	396	214
Spanish 2B	346	439	502	313
White Spanish	323	346	388	367

Several interesting relationships are shown by these data. The highest oil yield of 502 pounds per acre was obtained from Spanish 2B

fertilized with gypsum and potash. The two next highest combinations, which yielded essentially the same, are Spanish 2B fertilized with gypsum, 439 pounds, and Virginia Bunch fertilized with gypsum and potash, 435 pounds. It will be noted that the White Spanish variety, which is usually thought of as the best for oil production, yielded as a maximum only 388 pounds per acre. The lowest yields were obtained from the Virginia Bunch variety when it was unfertilized or treated with limestone and potash.

SUMMARY AND CONCLUSIONS

Although certain effects of calcium and potassium on kernel development and yield of large-seeded type peanuts have been determined, the effects of these elements on peanuts of smaller seed size have not been thoroughly investigated.

To compare the behavior of four varieties which differed widely in type and seed size to the addition of calcium and potassium, field investigations were undertaken on soils low in these elements. The soils selected represented those commonly encountered in the southern Coastal Plain area of North Carolina. They were somewhat lower in fertility and calcium levels than those characteristic of the older peanut area of this state. The four varieties selected were Virginia Bunch, North Carolina Runner, Spanish 2B, and White Spanish. Four fertilization variables were superimposed on each variety, *viz.*, no treatment, gypsum, gypsum plus potash, and limestone plus potash. The effects of these treatments upon each variety were determined by measuring yield, true shelling percentage, and percentage of the ovarian cavities filled.

The most striking feature of the results was the pronounced difference that the four varieties exhibited in their requirements for calcium. Virginia Bunch was found to have by far the highest calcium requirement of any of the varieties used. At one location, for example, yield of this variety was increased nearly six fold by the application of gypsum, that of North Carolina Runner nearly two fold, whereas those of Spanish 2B and White Spanish were not appreciably affected. The effect of calcium on the quality of fruit of each of the varieties at the same location is shown by the following increase in percentage cavities filled which were obtained by the use of gypsum: Virginia Bunch, 35.5; North Carolina Runner, 24.8; Spanish 2B, 19.0; and White Spanish, 4.6.

The increases in yield from added potash were small in comparison with those obtained by the use of gypsum. There was little difference in varietal response to potash additions, although North Carolina Runner tended to respond somewhat less than the other varieties. Potassium had no beneficial effect on kernel development and its addition resulted in increased yields through its effect on plant size. This behavior is in marked contrast to that of calcium, in which yields were increased through the beneficial effects of this element on kernel development.

The oil content of large and medium kernels was affected comparatively little by fertilization or by variety. In general, however,

the kernels from fruit of a high shelling percentage were somewhat higher in oil than those from fruit of lower quality. The yield of oil per acre is essentially a function of pounds of plump kernels produced.

When all the results of this study are considered, it is evident that peanut breeding and soil fertility programs are virtually inseparable. Recognition of differences in fertilizer practice and soil characteristics, particularly with respect to calcium, are essential for research in peanut breeding. Furthermore, problems in peanut nutrition cannot be attacked so successfully when differences in varietal behavior are disregarded.

LITERATURE CITED

1. BRADY, N. C., and COLWELL, W. E. Peanut yield and quality as affected by potassium and certain combinations of potassium, magnesium, and calcium. Jour. Amer. Soc. Agron., 37:429–442. 1945.
2. COLWELL, W. E., and BRADY, N. C. Soil fertility studies with peanuts. N. C. State Dept. Agr. Bul. Sept., 1943.
3. ———, ———. Studies on the effect of calcium on yield and quality of peanuts. Jour. Amer. Soc. Agron., 37:413–428. 1945.
4. GORE, U. R. Culture and fertilizer studies with peanuts. Ga. Agr. Exp. Sta. Bul. 209. 1941.
5. KITCHEN, C. W. U. S. standards for farmers' stock White Spanish peanuts. Mimeo release issued October 11, 1928; reissued, January 31, 1940.
6. ———. U. S. standards for farmers' stock runner peanuts. Mimeo release, issued September 1, 1931.
7. ———. U. S. standards for farmers' stock Virginia type peanuts. Mimeo release issued October 3, 1934; reissued, January 26, 1940.
8. MIDDLETON, G. K., and FARRIOR, J. W. Response of peanut varieties to different fertility levels. Assoc. Southern Agr. Workers Proc., 42:101–102. 1941.
9. WEST, H. O. Peanut production. Miss. Agr. Exp. Sta. Bul. 366. 1942.

DALLIS GRASS SEED SOURCES[1]

GLENN W. BURTON[2]

DALLIS grass, *paspalum dilatatum* Poir., ranks first among the perennial grasses that are being planted in improved pastures in the Southeast. Its palatability and nutritive value make this popularity well deserved. It is well adapted to lowland and fertile upland soils but cannot compete with some of the other grasses on soils low in fertility.

Many of the Dallis grass plantings made in recent years have failed. Perhaps first among the factors that have contributed to these failures has been the poor quality of the seed planted. Ergot, *Claviceps paspali* Stevens and Hall., a fungous disease that destroys the seeds, has been largely responsible for this poor quality and indirectly for the high price that Dallis grass seed has commanded. Inadequate fertilization of the poorer soils and anthracnose, caused by *Colletotrichum graminicolum*, have also hindered establishment and have caused good stands to die out and to be replaced by other grasses.

During the past 8 years a careful study of this species has been made in an effort to determine to what extent the problems just mentioned might be solved by the plant breeder. It is the purpose of this paper to report some of the findings of this study.

MATERIALS AND METHODS

A 3 × 3 foot spacing of individual seedling plants was used for studying the variability within different lots and strains of Dallis grass. The plants for these studies were established in the greenhouse as follows: In January or early February each lot of seed was planted in a separate pan of steam-sterilized soil. When the seedlings in these pans had developed their third leaf, they were transplanted individually to 2-inch clay pots of sterile soil. These were placed in well-rotted saw dust, were well fertilized, and were held in the greenhouse for about 3 months before they were transplanted in the field. This technic produced large plants that could be transplanted to the field without loss, giving the desired perfect stands without replanting.

In the fall of 1941 an experiment was designed to determine the variability within and between different seed sources of Dallis grass. Seed lots from South Africa, Uruguay, Australia, and the principal seed-producing areas in the United States were obtained. On May 21, 1942, seedlings from 24 different seed sources were space-planted in four-plant family rows replicated 10 times. On April 29 of the same year, 10 of these strains were seeded in 4 × 18 foot plots replicated six times. The weed growth on these plots was mowed several times in 1942, and in 1943 and 1944 yields of dry matter were obtained by clipping the plots at 2-week intervals with a power lawn mower.

In making the yield and green growth ratings on the spaced plantings, each plant was rated from 1 to 5 on the basis of its relative size and amount of green foliage, the best plants receiving a rating of 1. In the last two ratings plants nearly dead were rated 6 and dead plants were rated 7. The total rating for the

[1]Cooperative investigations at Tifton, Georgia, of the Division of Forage Crops and Diseases, Bureau of Plant Industry, Soils and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture, the Georgia Coastal Plain Experiment Station, and the Georgia Experiment Station. Received for publication January 31, 1945.

[2]Geneticist, U. S. Dept. of Agriculture, Tifton, Ga. The writer gratefully acknowledges the contributions of Dr. Bernardo Rosengurtt, Estacion Juan Jackson, Uruguay; Snelson Seed Co., Savannah, Ga.; and R. E. Lambert and Sons, Darlington, Ala., in supplying most of the seed lots included in this study.

four plants in each family row was then determined and these totals were subjected to statistical analyses. The mean four-plant total for each strain appears in Table 1.

On July 14, 1942, a long and a short glassine bag were placed on single panicles on each of two different plants in each four-plant row of the space-planted strain test. When mature, these heads were harvested and the number of caryopses produced on each panicle was determined. Open-pollinated panicles were also harvested from each bagged plant, but most of them were not analyzed because they were heavily infected with ergot. Since there were no consistent differences between the number of caryopses formed under short and long bags, all of the data were pooled to furnish the mean values in Table 1.

All seed of the current season was harvested from each plant in the space-planted strain test on August 7, 1943. When dry, each seed lot was threshed, screened, and placed in a properly labeled coin envelope. The technic used in arriving at the percentage of heavy florets and the number of ergots in 100 heavy florets has been described elsewhere.[3]

Correlation coefficients have been calculated to show the relationship between a number of the characters considered in this study. Due to the manner in which the yield ratings were taken and are presented, correlations between them and actual yields give negative coefficients when the relationship is obviously a positive one. Therefore, in an effort to avoid confusion, plus and minus signs have purposely been omitted from the r values included in this paper.

RESULTS

A Dallis grass disease survey made in the summer of 1936 revealed that occasional isolated plants of Dallis grass growing along roadsides were free of ergot but that all plants in pastures or rather dense plantings were heavily infected. In 1937, some 4,000 Dallis grass seedlings coming from commercial seed lots and the isolated plants found to be free of ergot in 1936 were space-planted for study. These 4,000 plants were found to be remarkably uniform in growth habit and were all heavily infected with ergot.

In 1938, seed of four strains of Dallis grass, reported to be resistant to ergot, were obtained from T. C. Seccombe, Coffs Harbour, N. S. W., Australia. Space plantings of these strains interplanted with a Hamburg, Louisiana strain were carefully studied in 1938. All plants in this test were found to be uniform in type and appeared to be equally susceptible to ergot.

By fall of 1939 most of the plants in the 1937 Dallis grass planting had died. Before destroying this planting, an unusually vigorous plant was taken to the greenhouse for seed increase. This plant came from seed harvested in the vicinity of Tifton, Ga. In the spring of 1941 selfed seedlings from this plant were space-planted with five Australian introductions, P.I. 136834 to P.I. 136838, in short family rows replicated several times. By midsummer it was apparent that the Australian introductions were very similar to the other strains of Dallis grass that had been studied at Tifton. The local selection, D-1, however, was more erect in its growth habit and produced more leaves and fewer heads. The most striking difference in this test was the manner in which D-1 continued to grow until frost while the introductions ceased growth in August. Thus, D-1 became the first distinctly divergent type that had occurred in the

[3]BURTON, GLENN W. A technic for measuring ergot resistance in Paspalum species. Jour. Amer. Soc. Agron., 37:160–162. 1945.

Dallis grass studies. Representative plants of D-1 and one of the Australian introductions are shown in Fig. 1.

Since all of the D-1 plants were very uniform, it seemed advisable to blend them together in a strain. This was accomplished in the fall of 1941 by isolating D-1 plants from other Dallis grass in the vicinity by frequently clipping the other plants to prevent flowering. The open-pollinated seed from these D-1 plants, when thoroughly mixed, became the D-1 strain included in the seed source tests. Open-pollinated seed from the most vigorous of these plants became the D-2 selection entered in the spaced plant comparison.

FIG. 1.—Dallis grass plants photographed August 15, 1941. On the left is a plant of the Australian introduction P.I. 136837 and on the right a plant of the leafy, anthracnose-resistant D-1 strain.

The results of the space-planted strain (seed source) test are summarized in Table 1. Since highly significant F values for strains were obtained for each of the 13 measurements, it may be concluded that the strains studied in this test differed significantly in forage yield, anthracnose resistance, self fertility under bag, heading date, ergot resistance, and longevity.

PLANT TYPE

The 24 strains in this test could be easily classified into three distinct plant types. Most of them were so similar in type that they could not be separated one from another. Since these strains were representative of the Dallis grass generally grown in the South, they were given the type name of common Dallis grass. D-1 and D-2 components of the anthracnose-resistant leafy group, differed from the common Dallis group by being much more resistant to anthracnose and by producing more leaves, fewer and more erect seed stalks, and somewhat smaller panicles (Fig. 1). Plants in the third group, characterized by the individual shown in Fig. 2, were much more erect and less leafy than the common or leafy groups. They also developed larger, much more pubescent florets and yellow anthers. (All plants in the first two groups had purple anthers.) All of the plants in P.I. 142259 and approximately three-fourths of the plants in

TABLE 1.—*The comparative response of 24 strains (seed sources) of Dallas grass when space planted in four-plant family rows replicated 10 times.**

Seed source	Estimated yield ratings				Amount of green growth rating, Sept. 7, 1943	Individual plant yields, grams		Number of caryopses per bagged panicle, July 14, 1942	Heading date 1943	Percentage of heavy florets by weight, 1943	Number of ergots in 100 heavy florets, 1943	Percentage mortality	
	July 14, 1942	Nov. 18, 1942	May 3, 1943	Nov. 1, 1944		Sept. 18, 1942	Aug. 7, 1943					Sept. 7, 1943	Nov. 1, 1944
Tifton, Ga., D-1	10.8	8.3	13.9	12.6	4.4	360	536	2.2	5-19	55.0	63.5	5.0	7.5
Tifton, Ga., D-2	9.7	8.5	9.1	12.8	4.7	426	611	3.0	5-18	53.3	61.4	5.0	7.5
Attalla, Ala.	7.8	9.2	10.2	20.9	11.5	532	688	6.5	5-10	56.3	65.1	0.0	35.0
Boligee, Ala.	9.2	13.6	17.9	23.7	15.9	474	429	4.9	5-13	56.9	70.4	17.5	52.5
Darlington, Ala.	8.1	9.2	13.3	21.6	12.9	578	594	4.2	5-10	56.4	63.2	5.0	35.0
Greensboro, Ala.	10.7	12.8	16.6	22.2	11.5	336	276	3.0	5-13	61.3	64.6	2.5	40.0
Grove Hill, Ala.	8.6	10.4	12.3	21.6	13.2	543	608	2.3	5-11	56.3	65.8	5.0	40.0
Montgomery, Ala.	8.0	8.9	11.8	19.3	11.9	550	679	4.8	5-12	54.3	64.3	2.5	22.5
Selma, Ala., lot 1	9.5	10.0	12.1	21.0	11.6	474	605	2.8	5-12	56.6	65.4	0.0	27.5
Selma, Ala., lot 2	9.6	10.3	13.3	22.4	11.4	438	599	5.5	5-11	58.3	65.2	12.5	42.5
Snowhill, Ala.	8.6	11.7	18.0	21.8	12.4	457	517	3.1	5-12	57.2	68.9	15.0	45.0
Pelahatchie, Miss.	7.3	11.9	15.3	22.7	12.5	515	534	6.1	5-13	58.5	68.1	5.0	40.0
West Point, Miss.	9.4	14.0	16.7	26.0	17.8	388	475	6.0	5-13	60.2	63.0	12.5	75.0
Hamburg, La	7.7	8.7	13.1	22.3	10.7	537	576	10.9	5-11	57.6	60.5	0.0	42.5
Plauchville, La.	7.6	10.1	12.5	20.8	12.1	552	563	8.2	5-11	57.7	61.8	2.5	32.5
Durham, N. C.	9.7	16.9	22.5	25.7	18.3	310	354	9.5	5-12	60.8	57.6	27.5	65.0
Australia, P. I. 136837	9.1	13.2	15.9	23.4	13.8	478	500	3.8	5-12	56.0	68.4	7.5	52.5
Melbourne, Australia.	8.1	10.7	11.9	20.9	12.3	538	573	9.0	5-12	56.7	65.8	2.5	27.5
South Africa	9.0	12.3	14.7	21.6	12.7	450	486	3.7	5-11	58.4	66.3	5.0	37.5
Uruguay, P. I. 142255	9.5	16.5	24.1	25.2	16.9	403	347	6.7	5-11	47.7	58.8	15.0	70.0
Uruguay, P. I. 142256	9.7	18.2	25.7	26.5	19.8	393	229	7.3	5-10	57.0	62.2	35.0	77.5
Uruguay, P. I. 142257	9.3	12.8	14.3	20.3	16.1	436	307	30.2	5-11	70.5	36.6	12.5	65.0
Uruguay, P. I. 142258	9.4	12.1	13.8	21.6	16.1	435	514	23.7	5-12	66.9	32.9	12.5	37.5
Uruguay, P. I. 142259	10.3	11.9	15.8	22.7	18.1	364	498	30.9	5-14	66.8	25.9	27.5	55.0
Least significant 5% mean difference	1.6	2.4	4.9	2.5	2.3	107	142	5.8	1.4 days	4.7	7.5	13.0	22.0

*The green growth rating is an index of anthracnose resistance. The lower the yield and green growth ratings, the greater the yield and amount of green growth.

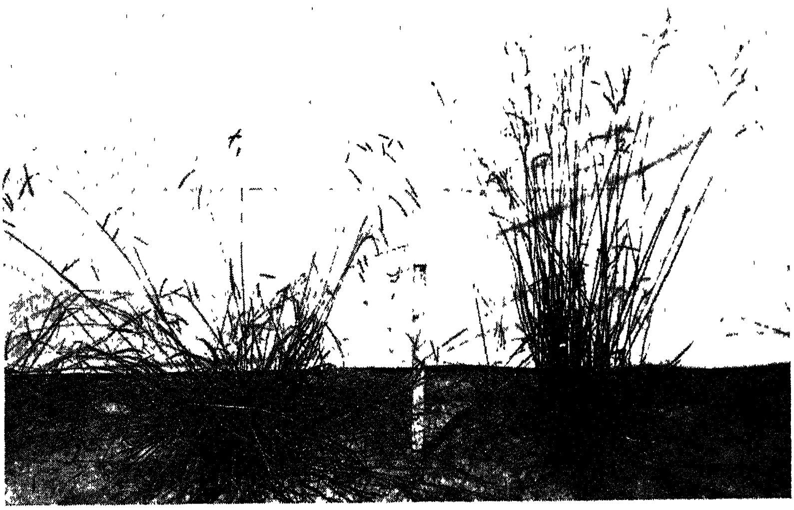

FIG. 2.—Dallis grass plants photographed September 16, 1942. From left to right occur representatives of the common and erect yellow-anthered groups, respectively.

P.I. 142257 and 142258 fell into this yellow-anthered group. The other plants from the Uruguayan seed lots, including all of P.I. 142255 and 142256, were similar to common Dallis grass in growth habit.

The mixtures of common and yellow-anthered types in P.I. 142257 and 142258 have been described. All plants within any one of the other 22 strains were remarkably uniform in plant type.

PLANT YIELD

Four yield estimates and two actual plant yields were made for each plant in this study. These data, summarized in Table 1, indicate that different seed sources do differ in yielding ability. That close relations exist between the mean yield estimates and actual yields is shown by the highly significant correlation coefficient of 0.88 obtained between the July 14, 1942, rating and the September 18, 1942, actual yield. A somewhat lower positive correlation of .64 was obtained between the actual yields taken in 1942 and 1943 because some strains, particularly D-1 and D-2, increased noticeably in yielding ability with time, while the Greensboro, Ala., strain and several of the Uruguayan strains lost vigor. It may be concluded, therefore, that the yielding ability of Dallis grass strains cannot be adequately evaluated in the first year of testing.

The close agreement between the two Selma, Ala., seed sources in yield performance and all other measurements is most interesting. Since these strains were obtained from two different seedsmen, it appears that they either came originally from the same field or that the Dallis grass growing in the vicinity of Selma is very uniform with respect to the characters studied in this test.

ANTHRACNOSE RESISTANCE

Anthracnose attacks the leaves and stems of Dallis grass in the summer and early fall, creating large lesions that frequently girdle and kill most of the above-ground parts. As a result, susceptible plants that have not been clipped or grazed become so weakened that they make very little growth and sometimes die. Consequently, the amount of late summer growth is closely associated with anthracnose resistance and may be used as an index of resistance to this disease. On September 9, 1943, approximately 1 month after all plants had been cut for yield determinations, each plant was rated from 1 to 6 on the basis of the amount of green foliage that it had produced. The summary of these ratings, presented in Table 1, indicates that these strains differed very significantly in their resistance to anthracnose and in their ability to grow in late summer. It also shows that D-1 and D-2 were highly resistant to anthracnose while the strains from West Point, Miss., Boligee, Ala., Durham, N. C., and Uruguay appeared to be more susceptible than the others to this disease.

SELF FERTILITY

The self fertility of these 24 strains was studied in the summer of 1942 when single panicles on half of the plants in the spaced strain test were bagged with a long and a short glassine bag. A bad wind storm that bent many of the bagged culms and ergot which attacked the open-pollinated heads no doubt had considerable influence on the results obtained from this study. No ergot formed on the bagged heads, due no doubt to the isolation from the insect vectors that spread the infectious "honey dew". Forty-four per cent of the bagged panicles produced no caryopses. Since these occurred most frequently in strains that set very few seeds under bag, they were averaged with the caryopses counts to give the strain means presented in Table 1. It is recognized, however, that many of these failures to set seed may have resulted from injury incurred during the wind storm.

It is evident from the results summarized in Table 1 that the strains in this test differed in their ability to set seed under bag. Three of the introductions obtained from Uruguay were much more fertile than the others when bagged. They also produced significantly more open-pollinated seed per panicle than the other strains in the test.

Due to the disturbing influence of ergot upon seed setting[4] and the difficulty of separating caryopses from ergots, only 50 of the open-pollinated seed samples were analyzed for seed set. All but two of these panicles contained some caryopses. A statistical study of the seed set on these 50 plants gave for the bagged panicles an average of 9.8 caryopses and for the open-pollinated panicles an average of 18.9 caryopses. This difference far exceeded the 1% level of significance.

---

[4]BURTON, GLENN W. Factors influencing seed setting in several southern grasses. Jour. Amer. Soc. Agron., 35:465–474. 1943.

HEADING DATE

The small least significant mean difference of 1.4 days required for the heading date means is indicative of the uniformity in heading date exhibited by the plants within the various strains. A number of the strains differed significantly in the date when the first heads appeared, but D-1 and D-2 were the only strains that differed greatly from the others in this respect. They began to head approximately a week later than the other strains in the test.

ERGOT RESISTANCE

The three yellow-anthered strains from Uruguay produced a higher percentage of heavy florets by weight than any of the other 21 strains. They also were much more ergot resistant, producing only about one-half as many ergots per 100 heavy florets. These results suggest that these two characters are related. If all 24 strains are included in calculating the correlation coefficient, a significant value of .73 is obtained. If, however, the Uruguayan strains are not included in the calculation, a nonsignificant correlation of .20 is obtained. Thus, it may be concluded that within common Dallis grass there is no relation between the percentage of heavy florets by weight and the number of ergots in 100 heavy florets. Therefore, the percentage of heavy florets will throw no light upon the ergot resistance of common Dallis grass strains and need not be considered in making an appraisal of the ergot resistance of these strains.

The fact that several of the common Dallis strains produced significantly fewer ergots than others suggests that a program of careful testing and selection in existing ecotypes should result in the development of more ergot-resistant varieties. The degree of resistance shown by the common Dallis strains in this test, however, was small compared with that shown by the yellow-anthered strains from Uruguay. Perhaps, therefore, the greatest progress in breeding for ergot resistance may be made by hybridizing the ergot-resistant yellow-anthered strains with some of the best strains of common Dallis grass.

MORTALITY

The percentage mortality data summarized in Table 1 show that by fall of 1943 only 5 of the 24 strains differed significantly from the best in mortality. One year later, however, 19 of the 24 strains had experienced a significantly greater mortality than D-1 and D-2. The three common Dallis strains that failed to differ significantly from D-1 and D-2 in mortality came from Montgomery, Ala., Selma, Ala., and Melbourne, Australia. Since the mortality percentages for these three strains were over three times the mortality percentages for D-1 and D-2, it seems probable that in more critical tests they would have been significantly different.

Since neither the estimated yield made on July 14, 1942, nor the actual yield on Sept. 18, 1942, are significantly correlated with the percentage mortality of Nov. 1, 1944, it is evident that differences

in establishment and early vigor were not responsible for the striking variations in mortality that were obtained. The highly significant correlation of .87 obtained between the amount of green growth on Sept. 7, 1943 (the anthracnose resistance index) and percentage mortality on Nov. 1, 1944, indicates that the maintenance of stands in Dallis grass is closely associated with the resistance of the strain to anthracnose. The plant yield estimate on Nov. 18, 1942, in much the same manner as the amount of green growth on Sept. 7, 1943, should be an index of anthracnose resistance. The yield rating of Nov. 18, 1942, was closely correlated with the percentage mortality of Nov. 1, 1944, giving a correlation coefficient of .85. In both cases the mortality percentage decreased as the anthracnose resistance increased. Thus, it appears that selection in the first year of plants that make good fall growth and are anthracnose resistant will, in most cases, be selection for longevity.

REACTION WHEN CLIPPED FREQUENTLY

A summary of the production of 10 Dallis grass strains when seeded in broadcast plots and clipped frequently is presented in Table 2. It is apparent from these data that in 1943, except for the early summer period, the strains did not differ in productivity when clipped at 2-week intervals. In 1944, however, significant strain differences in yield of dry matter were obtained in all but the fall period. In this period the annual crab grass filled the spaces left by dying Dallis grass plants and made up a large percentage of the clippings on some plots.

An explanation for the lack of correlation between the 1943 and 1944 yields of clippings may be found in a study of the relation between stand and yield. In the spring of 1943 there was no noticeable difference in stand in the 10 Dallis grass strains and no significant differences in total yields were obtained in that year. On March 3, 1944, significant strain differences in stand were observed and these differences were closely related to the total 1944 yields, giving a highly significant positive correlation coefficient of .82. These observations suggest that the spring stand had a marked influence on the yields obtained during the remainder of the year.

The March 3, 1944, stand percentages from these plots give a highly significant coefficient of .89 when correlated with the amount of green growth ratings for Sept. 7, 1943, for the same strains grown in the space-planted test. Expressed more specifically, strains showing the most green growth on Sept. 7, 1943, maintained the best stands in seeded plots. Since the amount of green growth on Sept. 7, 1943, is a good index of anthracnose resistance, it appears that variations in the resistance of these 10 strains to this disease were largely responsible for the strain variations in stand and yield observed in the clipping test.

SPACED PLANTING VS. CLIPPING FOR EVALUATING STRAINS

There has been considerable speculation as to the usefulness of the spaced plant test in evaluating strains of forage plants for pasture purposes. The relationship between the response of different strains

TABLE 2.—*The comparative production and stand of 10 strains of Dallis grass seeded in small replicated plots on April 29, 1942, and clipped frequently with a power lawn mower.*

Seed source	Pounds of dry matter per acre for the period										Estimated percentage stand, Mar. 31, 1944	Percentage green tissue Nov. 1, 1944*
	1943					1944						
	June 1, to 23	July 6 to Aug. 4	Aug. 18 to Sept. 15	Sept. 29 to Nov. 10	Total	Apr. 11 to May 23	June 6, to July 18	Aug. 1, to Sept. 12	Sept. 28 to Nov. 14	Total		
Tifton, Ga., D-1	159	294	342	105	900	344	1,161	873	146	2,524	95.8	73.5
Australia, P. I. 136837	174	363	297	114	948	264	1,075	809	153	2,301	80.8	26.2
Melbourne, Australia	195	330	315	99	939	409	1,421	809	132	2,771	92.5	36.7
South Africa	189	435	351	108	1,083	316	1,204	764	158	2,442	86.7	31.7
Uruguay mixture	150	387	297	120	954	215	1,006	743	175	2,139	74.2	16.2
Plauchville, La.	207	357	315	99	978	290	1,160	828	170	2,448	86.7	38.5
West Point, Miss.	183	429	282	102	996	232	1,035	698	146	2,111	80.0	27.2
Pelahatchie, Miss.	171	387	318	99	975	285	1,126	769	134	2,314	87.5	20.2
Darlington, Ala.	174	303	312	93	882	343	1,118	865	181	2,507	88.3	34.5
Attalla, Ala.	171	324	327	93	915	312	1,170	862	151	2,495	87.5	42.2
Least significant 5% mean difference	NS†	64	NS	NS	NS	90	192	112	NS	322	9.0	18.0

*The percentage of the points on a point quadrat that touched green Dallis grass tissue. Four random stations in each plot were averaged in arriving at these values.
†NS = Not significantly different.

when grown in spaced plant tests and when clipped should indicate the weight that may be given to results obtained from space-planted progenies. Obviously, the nature of the test and the material being tested will influence the results.

Correlation coefficients have been calculated to show the relation between the response of 10 Dallis grass strains when grown in spaced plant and clipping tests. Between the amount of green growth rating on Sept. 7, 1943, in the space test and the percentage stand in the plots March 31, 1944, a highly significant correlation of .89 exists. A correlation of the same magnitude was obtained between the green growth rating of Sept. 7, 1943, and the percentage of green tissue in the plots on Nov. 1, 1944. It is evident, therefore, that strains capable of making good fall growth in spaced plant tests will do likewise in seeded plots. They will also maintain better stands when grown in broadcast plantings.

A highly significant correlation of .82 was obtained between the percentage of living spaced plants on Nov. 1, 1944, and the percentage of green tissue in the clipped plots on Nov. 1, 1944. Thus, it appears that longevity measurements obtained from space-planted Dallis grass strains may be expected to apply when they are clipped to simulate grazing.

The positive correlation coefficient of .66 obtained between the Aug. 7, 1943, spaced plant yields and the total 1944 clipping yields exceeded the 5% level of significance. Although this correlation is low, it is interesting to note that the five lowest yielding strains in the spaced plant test were likewise the lowest yielding strains in the clipped plot test. Expressed in another way, the lowest yielding half of these 10 strains could have been discarded on the basis of the Aug. 7, 1943, spaced plant yield without losing any of the five most productive strains in the clipped plot test.

It may be concluded, therefore, that a spaced plant test, such as the one described here, will be very useful in evaluating Dallis grass strains. Such a test will give ratings on anthracnose resistance, fall growth, longevity, and yield which may be expected to apply reasonably well when the strains are grown in broadcast plantings. The spaced plant test requires less seed, land, and labor than the clipped plot test and frequently all of these items are scarce in a forage breeding program. It also facilitates the study of the flowering and seeding characteristics and the ergot resistance of each strain. In addition, the spaced plant test furnishes some information that the clipped plot test can not furnish, such as a knowledge of the uniformity and breeding behavior of each strain. On the other hand, the reaction of the strain with other species must be studied in broadcast plots. The best testing technic would seem to involve the use of the spaced plant test to evaluate all strains and to eliminate all but a few of the best ones. These might then be tested alone and in association with other species in a clipped plot test.

DISCUSSION

None of the Dallis grass strains included in these tests were outstanding in all characteristics. They did differ sufficiently, however,

to warrant further testing in order to direct only the best strains into commercial seed channels.

The truly superior Dallis grass will combine the ergot resistance and fertility of the yellow-anthered Uruguayan strains and the leafiness, anthracnose resistance, and longevity of D-1 and D-2 with the productivity of some of the best strains of common Dallis grass. The development of this strain will require time and the best efforts of the plant breeder as he manipulates the building blocks that this study has discovered.

SUMMARY

1. Twenty-four strains or seed sources of Dallis grass coming from South Africa, Uruguay, Australia, and the principal seed-producing areas in the United States were compared in a spaced plant test at Tifton, Ga. Ten of them were also evaluated in a clipped plot test. Statistically significant strain differences in forage yield, anthracnose resistance, self fertility under bag, heading date, ergot resistance, and longevity were observed.

2. The 24 strains fell into three distinct plant types. Nineteen, so similar they could not be separated one from another, made up the common Dallis grass group. D-1 and D-2, components of the leafy group, differed from the common Dallis group by being much more resistant to anthracnose and by producing more leaves, fewer and more erect seed stalks, and somewhat smaller panicles. The yellow-anthered type, in addition to having yellow instead of purple anthers, was more erect, less leafy, and developed larger, more pubescent florets than the other two types.

3. Mixtures of common and yellow-anthered types occurred in two introductions. All plants within any one of the other 22 strains were remarkably uniform in plant type.

4. Small but significant differences in ergot resistance occurred between different strains of common Dallis grass. The yellow-anthered strains from Uruguay were much more resistant to ergot than any of the other strains tested.

5. Anthracnose resistance indices were very closely correlated with longevity and stand variations, indicating that anthracnose-resistant strains will tend to live longer and maintain better stands than strains susceptible to this disease.

6. Evidence is presented to indicate that a spaced plant Dallis grass strain test will give ratings on anthracnose resistance, fall growth, longevity, and yield which may be expected to apply reasonably well when the strains in question are compared in a clipped plot test.

STUDIES ON SAMPLE SIZE AND NUMBER OF REPLICATES FOR GUAYULE INVESTIGATIONS[1]

WALTER T. FEDERER[2]

WHENEVER experimental work is started on a new crop it is desirable to determine sample size and number of replicates necessary to obtain reliable means. This is particularly true for a crop such as guayule in which the variability due to genetic differences is large. The standard error of a variety or treatment mean usually can be decreased more rapidly by increasing the number of replicates rather than increasing the number of plants per plot. The purpose of this study is to determine the most efficient distribution of plants and replicates to obtain the maximum amount of information per plant sampled.

MATERIAL AND METHODS

Seven varieties or strains of guayule, 109, 130, 405, 406, 407, 416, and 593, were employed in this study. Since some of these varieties differ widely in morphological and physiological characters, the results of this study may be expected to have more general application than if one variety or like varieties were used. The more important economic plant characters, percentage of rubber per plant, dry weight of shrub per plant, and weight of rubber per plant, were used in this study. The latter two characters were recorded in grams. Weight of rubber per plant is the product of percentage of rubber and dry weight of shrub.

The design of the experiment was a randomized complete block with 27 replicates per variety. Two plants were sampled from each 1/40-acre plot. These two plants were selected at random but with the restriction that they be surrounded by a full stand. This restriction was employed to avoid the influence that extra area (caused by missing plants) might have on the characters studied. This makes the study applicable to the stands of guayule that may be expected in the future (4).[3] The experimental material was transplanted from the guayule nurseries for field plantings to the experimental area at Salinas, Calif., in April, 1943. The harvesting or sampling was performed during February, 1944.

In the following discussion the plants in a plot are designated as the sample. Thus the two plants in each plot are the sample while the individual plants are the sampling units.

The separate components of variation present in this experiment are estimated by the method set forth by Winsor and Clarke (10). This method and the theory involved is an extension of the suggestions of Fisher (2) in the development of the analysis of variance. The theory involved will be discussed only as far as necessary to clarify the formulae, symbols, and the extension of this procedure. Snedecor (9), King and Jebe (5), King, McCarty, and McPeek (6), and Jessen (3) have used this method in testing the efficiency of the distribution of size and number of samples.

The symbols v, r, and p are explained in Table 1. The symbols V, R, E, and S represent population variances which are parameters or expected values. S is the sampling error or the variance between plants of the same sample. E is the additional component of variance in experimental error or the failure of the

[1]Contribution from the Guayule Research Project, U. S. Dept. of Agriculture, Salinas, Calif. Received for publication February 14, 1945.

[2]Formerly Associate Geneticist, U. S. Dept. of Agriculture, Agricultural Research Administration, Bureau of Plant Industry, Special Guayule Research Project; now Associate Agricultural Statistician, U. S. Dept. of Agriculture, Bureau of Agricultural Economics, Division of Agricultural Statistics. For their helpful suggestions and criticisms, the writer extends his thanks to LeRoy Powers, to the Statistical Laboratory at Iowa State College, and to the others who reviewed this paper.

[3]Figures in parenthesis refer to "Literature Cited", p. 478.

variety differences to remain the same in the several replicates. V and R are components added by varieties and replicates peculiar to this experiment. Thus these two components, V and R, are of interest if it is desired to re-estimate the varietal and replicate differences with the particular varieties at a particular location. In the event that another like sampling was performed on this experiment, V and R would become of interest to the experimenter in the estimation of V and R from repeated samplings in this population of varieties at this location. Since E and S are estimates of variances which are random components, they are of more general interest as they apply to guayule varieties grown in any location. These separate components are estimated from the formulae presented in Table 1.

TABLE 1.—*Analysis of variance with theoretical mean squares and error variances.*

Source of variation	Number in each	Degrees of freedom		Theoretical mean square	Error variance
Varieties	v = 7	v−1 =	6	S+pE+rpV	S/rp+E/r+V
Replicates	r = 27	r−1 =	26	S+pE+vpR	S/vp+E/v+R
Var.×rep.	—	(v−1) (r−1) =	156	S+pE	S/rp+E/r
Plants per sample	p = 2	(p−1) =	1	—	—
Plants within samples	—	rv(p−1) =	189	S	—
Total	rvp = 378	rvp−1 =	377	Total variance	

In any experiment the investigator is interested in those mean squares which are to be used in tests of significance. In this experiment, the mean square for plants within samples or the sampling error, S, with rv (p–l) or 189 degrees of freedom provides an estimate of error for testing the mean square for the interaction of varieties and replicates. The ratio $F = \dfrac{S + pE}{S}$ furnishes a test of the hypothesis that E = O. In turn the interaction mean square of varieties and replicates is the error term used for testing the mean square for varieties and for replicates. The ratio $F = \dfrac{S + pE + rp\,V}{S + pE}$ is a test of the hypothesis that V = O. In like manner $F = \dfrac{S + pE + vp\,R}{S + pE}$ tests the hypothesis that R = O.

The interaction mean square for varieties and replicates or S + pE is the experimental error which is used in testing the mean squares for varieties and for replicates. Since there are rp plants of each variety, the variance of variety means is S/rp + E/r. The square root of this term is the standard error of variety means.

PRESENTATION AND DISCUSSION OF RESULTS

The analysis of variance for each of the three plant characters, rubber percentage, dry weight of shrub, and weight of rubber, on seven varieties of guayule is presented in Table 2. For rubber percentage the differences between variety means and between replicate means are significant. Thus the hypotheses that V = O and R = O are rejected as they have a very low probability of being true. Therefore the differences between variety means and between replicate means are considered to be real rather than chance deviates. (See Federer (1) for a comparison of these means.) For dry weight of shrub the experimental error mean square is significant. In this

case, the hypothesis that E = O is rejected. Likewise for weight of rubber the hypothesis that V = O is rejected. The differences between variety means for grams of rubber are considered to be real rather than sampling variations.

From the error mean squares obtained in this experiment, the estimated components of variance are given in Table 2 for each of the plant characters. The magnitude of these components or the variance from the different sources varies considerably. S or the variance between plants is quite large when compared to E. This would indicate that a considerable reduction in the variance of the means could be obtained by increasing the number of plants per sample. The effect of reducing S and E will be illustrated in Table 3.

The error mean square per replicate is obtained by multiplying the error mean square of a variety mean by the number of replicates; thus, $r(S/rp + E/r) = S/p + E$. Using this formula p was varied to determine the effect of the different values of p on the error mean square per replicate. When r is varied or nine replicates are used instead of 27 and when the number of plants sampled per variety is kept constant, the E component in the experimental error for nine replicates is three times the E component for 27 replicates if both are on the same basis. Thus $27 \frac{S}{(9)(6)} + \frac{E}{9} = S/2 + 3E$ or $S/p + 3E$ for the general case. These error mean squares are now directly comparable.

TABLE 2.—*Analysis of variance on percentage rubber, dry weight of shrub, and weight of rubber per plant for one year old guayule.*

Source of variation	Degrees of freedom	Mean square	Theoretical mean square	Estimates of
		Percentage of Rubber per Plant		
Varieties......	6	14.9800**		
Replicates.....	26	.9812*		
Var.×reps....	156	.5538	S+2E	E= .0167
Between plants	189	.5205	S	S= .5205
		Dry Weight of Shrub per Plant		
Varieties......	6	1239.51		
Replicates.....	26	2055.29		
Var.×reps....	156	1890.55*	S+2E	E= 228.01
Between plants	189	1434.54	S	S=1434.54
		Weight of Rubber per Plant		
Varieties......	6	14.8400*		
Replicates.....	26	7.2865		
Var.×reps....	156	5.9424	S+2E	E= .5489
Between plants	189	4.8446	S	S= 4.8446

*F >.05 level of probability.
**F >.01 level of probability.

The total number of plants sampled per variety is presented in Table 3 for each of the three plant characters studied. The number

TABLE 3.—*Estimated variance per replicate, relative efficiency based on obtained variance, coefficient of variation, and standard error in percentage of the mean for different sample sizes and number of replicates for one-year-old guayule on three plant characters.*

Number of plants sampled per variety	9 replicates						27 replicates					
	Number of plants per sample	Error mean square per replicate	Percentage efficiency based on 2-plant sample	C.V.*	Standard error in percentage of mean	Number of plants per sample	Error mean square per replicate	Percentage efficiency based on 2-plant sample	C.V.*	Standard error in percentage of mean
					Percentage Rubber per Plant					
9	1	.5705	49	12.4	4.15	—	—	—	—	—
18	2	.3103	89	9.2	3.06	—	—	—	—	—
27	—	—	—	—	—	1	.5372	52	12.1	2.32
36	4	.1802	154	7.0	2.33	—	—	—	—	—
54	6	.1368	202	6.1	2.03	2	.2769†	100	8.7	1.67
72	8	.1151	241	5.6	1.86	—	—	—	—	—
108	12	.0934	296	5.0	1.68	4	.1468	189	6.3	1.21
216	24	.0717	386	4.4	1.47	8	.0817	339	4.7	0.91
324	36	.0645	429	4.2	1.39	12	.0601	461	4.0	0.78
432	48	.0609	455	4.1	1.36	—	—	—	—	—
648	72	.0573	483	3.9	1.31	24	.0384	721	3.2	0.62
1,296	—	—	—	—	—	48	.0275	1,007	2.7	0.53

Dry Weight of Shrub per Plant

9	1	2118.55	45	50.6	16.87	—	—	—	—	—
18	2	1401.29	67	41.2	13.72	—	—	—	—	—
27	—	—	—	—	—	1	1662.54	57	44.8	8.63
36	4	1042.65	91	35.5	11.84	—	—	—	—	—
54	6	923.11	102	33.4	11.14	2	945.27†	100	33.8	6.51
72	8	863.33	109	32.3	10.77	—	—	—	—	—
108	12	803.56	118	31.2	10.39	4	586.64	161	26.6	5.13
216	24	743.79	127	30.0	10.00	8	407.32	232	22.2	4.27
324	36	723.87	131	29.6	9.86	12	347.55	272	20.5	3.95
432	48	713.90	132	29.4	9.79	—	—	—	—	—
648	72	703.94	134	29.2	9.73	24	287.78	328	18.7	3.59
1,296	—	—	—	—	—	48	257.89	367	17.7	3.40

Weight of Rubber per Plant

9	1	6.4914	46	47.1	15.70	—	—	—	—	—
18	2	4.0691	73	37.3	12.43	—	—	—	—	—
27	—	—	—	—	—	1	5.3935	55	42.9	8.26
36	4	2.8579	104	31.3	10.42	—	—	—	—	—
54	6	2.4542	121	29.0	9.65	2	2.9712†	100	31.9	6.13
72	8	2.2523	132	27.7	9.25	—	—	—	—	—
108	12	2.0505	145	26.5	8.82	4	1.7601	169	24.5	4.72
216	24	1.8486	161	25.1	8.38	8	1.1545	257	19.9	3.82
324	36	1.7813	167	24.7	8.22	12	.9526	312	18.0	3.47
432	48	1.7477	170	24.4	8.15	—	—	—	—	—
648	72	1.7140	173	24.2	8.07	24	.7508	396	16.0	3.08
1,296	—	—	—	—	—	48	.6498	457	14.9	2.87

*Coefficient of variation.
†Obtained error mean square per replicate.

of plants per sample, the estimated error mean square per replicate (on the same basis as the base which is 27 replicates with two plants per sample), the percentage efficiency of the error mean square relative to the base, the coefficient of variation, and the estimated standard error in percent of the mean are presented in Table 3 opposite the total number of plants sampled per variety for both the nine and 27 replicate group. The number of plants per sample was varied as shown in Table 3.

The error mean square per replicate for percentage rubber for the two plant sample with 27 replicates is $S/2 + E = .5205/2 + .0167 = .2769$. The values of E and S are obtained from Table 2. Doubling p cuts the variance of a single sample mean, S/p, in half. When four plants per sample are sampled instead of two plants, the variance is $S/4 + E = .5205/4 + .0167 = .1468$ for percentage rubber. The relative efficiency of the four plant sample to the two plant sample is $\frac{S/2 + E}{S/4 + E} \times 100 = \frac{.2769}{.1468} \times 100 = 189\%$. This is a gain in statistical efficiency of 89% over the two plant sample.

For nine replicates with two plants per sample for percentage rubber, the error mean square per replicate is equal to $S/2 + 3E = .5205/2 + 3(.0167) = .3103$. The relative efficiency of this design to the base is equal to $\frac{S/2 + E}{S/2 + 3E} \times 100 = \frac{.2769}{.3103} \times 100 = 89\%$ or a decrease of 11% in statistical efficiency. The remainder of the variances and efficiencies were computed in like manner.

For the plant character percentage of rubber, the increase in number of plants per sample reduces the mean square considerably. A one-plant sample is about half, 52%, as efficient as the two-plant sample and the four-plant sample increased the precision over the two-plant sample by 89%. This tendency for increase in precision continues at a high rate. The reason for this is the difference in magnitude between S and E. The latter is very small and the former relatively large. Hence, any decrease in S is almost directly proportional to the amount of the increase in precision. Further, a decrease in the number of replicates from 27 to 9 with two plants per sample results in a decrease in precision of only 11%. This shows that the variation between the individual plants within a sample is large when compared to the variation between samples.

Twenty-seven replicates with eight plants per sample requires the same total number of plants as nine replicates with 24 plants per sample, but the relative efficiency of the former is 339% and of the latter, 386%. Thus for the same number of plants, 9 replicates with 24 plants per sample are more precise than 27 replicates with eight plants per sample. The relative efficiency of 27 replicates with 12 plants per sample is 461% and of 9 replicates with 36 plants per sample is 429%. Thus for the same number of plants harvested the former design is more efficient than the latter from the standpoint of precision. This is a reversal of the previous case where fewer replicates gave more precision. Somewhere between these two exam-

ples is the point at which the change should be made from sampling more plants per sample to increasing the number of replicates in order to obtain the most precision for a given number of plants.

The increase in number of plants sampled does not decrease the error mean square per replicate for grams of rubber per plant and dry weight of shrub as rapidly as it does for percentage rubber. Doubling the amount of plants sampled from two plants to four plants per sample with 27 replicates produces an increase in precision of 61% for dry weight of shrub and 69% for grams of rubber per plant. The variance between samples, 2E, is about one-third as large as the variation between plants for dry weight of shrub and about one-fourth as large for grams of rubber per plant. For dry weight of shrub and grams of rubber per plant 27 replicates with two plants per sample are nearly equal in precision to 9 replicates with six plants per sample. A four plant sample with 27 replicates is more precise than 9 replicates with 12 plants per sample. In other words, the most gain in precision for a design with 9 replicates and 8 or 12 plants per sample can best be obtained by increasing the number of replicates. This does not mean that the precision of the experiment cannot be increased by sampling more plants per sample. It does mean that the most gain in information for the same number of plants harvested can be obtained by increasing the number of replicates at this point.

In order to obtain an idea of the effect of these different sizes and number of samples in estimating the variety mean, the coefficient of variation and the standard error in percentage of the mean are presented. To make all sample sizes and numbers comparable, the standard deviation and the standard error were computed on the basis of the two-plant sample. The square root of the error mean square per replicate is the standard deviation. These statistics give an idea of the relative variability in percentage of the mean for the plant characters and designs presented in Table 3.

The standard deviation in percentage of the mean or the coefficient of variation is relatively low for percentage of rubber regardless of the size of sample or number of replicates. The decrease in the coefficient of variation is quite large when the number of plants was increased from one to two and then to four plants per sample regardless of whether there were 27 or 9 replicates. With eight plants per sample the decrease in the coefficient of variation levels off. Little decrease results when over 12 plants per sample are harvested. A small decrease in the coefficient of variation results when 27 replicates instead of 9 are used. In view of the relatively high variation in the other two characters, the refinement of the experiment for percentage rubber would be superfluous.

The standard error in percentage of the variety mean is the coefficient of variation divided by the square root of the number of replicates. This expression is of value in determining the difference required for significance. For percentage of rubber, the standard error in percentage of the variety mean is decreased very little when sample sizes larger than 8 or 12 plants are used. When differences of 2 to 4% of the mean are statistically significant, the experiment is

refined enough for most purposes. A comparison of the sample sizes yielding the same total number of plants for 9 replicates and 27 replicates indicates that the larger number of replicates is effective in reducing the difference required for significance.

The dry weight of shrub per plant is extremely variable in this experiment. The coefficients of variation ranged from 17.7% for the 48 plant sample with 27 replicates to 50.6% for the one-plant sample with 9 replicates. With nine replicates there is little that can be done toward decreasing the coefficient of variation by harvesting more than 12 plants per sample. The variability of the experiment for dry weight of shrub is decreased considerably by increasing the number of replicates, but even here more than 12 plants per sample did not decrease the variability to any great extent. Regardless of design it is quite apparent that the guayule plants from this test were extremely variable.

The standard error in percentage of the mean for dry weight of shrub varies from 3.40% for the 48-plant sample with 27 replicates to 16.87% for the one-plant sample with 9 replicates. The decrease in the standard error in percentage of the mean was rather large when the sample sizes were increased from one to two to four plants. After eight plants per sample, doubling the number of plants did not decrease the standard error so rapidly; instead, this decrease begins to level off. Therefore, with 12 or more plants per sample, the decrease in the standard error of the mean is not enough to warrant harvesting more plants per sample for either 9 or 27 replicates. The chart prepared by Powers (8) indicates that about 92% of the genetic variability within a plot is accounted for when 12 plants per plot are sampled. A comparison of the sample sizes for an equal number of plants harvested reveals the effect of the increased number of replicates on the standard error of a variety mean. From the 27 replicate group, the 2-, 4-, 8-, 12-, and 24-plant samples give the same total number of plants, respectively, as the 6-, 12-, 24-, 36-, and 72-plant samples from the 9 replicate group. The standard error of any particular member of the 27 replicate group cannot be obtained by multiplying that of the corresponding 9 replicate group by $\sqrt{3}$. For those in the 27 replicate group it is the $\sqrt{3}$ times the effect of reducing the variability between samples, E/r, minus the effect of increased variation between plants within a sample S/rp. This brings out the relationship between sample size and number of replicates as it affects the error mean square per replicate.

The variability of these guayule strains with respect to dry weight of shrub is reflected in grams of rubber per plant. The variability of grams of rubber per plant is almost as high as dry weight of shrub. The same comparisons that are made on dry weight of shrub apply for grams of rubber per plant. In light of this, it is evident that increased precision for grams of rubber per plant must come from more accurate determinations of dry weight. The relative uniformity of these strains for percentage rubber had little effect in reducing the variability in grams of rubber per plant.

In order to obtain means of equal accuracy for percentage rubber and dry weight of shrub, a larger sample is required for the latter

character. Of course the limits of accuracy desired by the sampler determines the size of the sample. For example, suppose the sampler desired to estimate the true mean within 8.5%. That is, it would be desired to estimate the true mean within 8.5% 19 times out of 20. Twice a standard error of 4.25% equals 8.5%. For percentage rubber nine replicates with one plant per sample gave a standard error that was about 4.25% of the mean. The comparable standard error for dry weight of shrub was obtained from 27 replicates with eight plants per sample. In this case it requires 24 times as many plants to give the same degree of accuracy for dry weight of shrub as it does for percentage rubber.

From these data it is evident that there is a relatively low amount of variability for percentage rubber within a variety. Also, there is a large amount of diversity between individual plants of a variety for dry weight of shrub. The variability of this character is reflected in weight of rubber per plant. In studying characters such as dry weight of shrub and weight of rubber in guayule as heterogeneous as these strains, it is necessary to use a large number or replicates to obtain a reliable estimate of a variety or treatment mean. Leonard and Clark (7) state that as a rule little is to be gained by the use of more than 10 replicates in field trials. The varieties of guayule used in this experiment appear to be an exception to this general rule when dry weight of shrub and weight of rubber per plant are being studied.

This gives the experimenter in guayule an estimate of the variability present for these three plant characters. This information can be of material aid in designing an experiment for this or a similar crop. The number of replicates used will be determined by the limits of accuracy desired.

SUMMARY AND CONCLUSIONS

Statistical studies on data involving seven guayule strains for such plant characters as percentage of rubber, dry weight of shrub, and weight of rubber were conducted to determine the effect of size and number of samples on the experimental error. From these studies the determinations of the variance from each source are considered quite accurate in view of the large number of replicates employed. It is concluded for the 1-year guayule grown in this experiment that:

1. Significant differences existed between variety means for percentage of rubber and grams of rubber per plant.
2. The variability within the varieties for dry weight of shrub was much higher than for percentage of rubber.
3. The variability in grams of rubber per plant was nearly equal to that found in dry weight of shrub. The relative uniformity of percentage of rubber had little effect on the variability of grams of rubber per plant.
4. Little increase in precision in the experiment could be gained by harvesting more than 12 plants per sample.
5. For percentage rubber, nine replicates with 12 plants per sample gave an estimate of the standard error of the variety mean which was 1.68% of the mean.

6. For dry weight of shrub and grams of rubber per plant, a large number of replicates, 27, and a 12-plant sample were required to give an estimate of the standard error of the variety mean which was 3.95% of the mean.

7. For these data it required 24 times more plants for dry weight of shrub than for percentage of rubber to obtain a standard error that was about 4% of the mean.

LITERATURE CITED

1. FEDERER, W. T. Variability studies on seed, seedling, and young plant characters of varieties and strains of guayule, *Parthenium argentatum* Gray. (In Press).
2. FISHER, R. A. Statistical Methods for Research Workers. Edinburgh: Oliver and Boyd. Ed. 5. 1934.
3. JESSEN, R. J. Statistical investigation of a sample survey for obtaining farm facts. Iowa State College Res. Bul. 304. 1940.
4. KELLEY, O. J., HUNTER, A. S., and HOBBS, C. H. The effect of moisture stress on nursery-grown guayule with respect to the amount and type of growth response on transplanting. Jour. Amer. Soc. Agron., 37:194–216. 1945.
5. KING, A. J., and JEBE, E. H. An experiment in pre-harvest sampling of wheat fields. Iowa State College Res. Bul. 273. 1940.
6. ————, MCCARTY, D. E., and MCPEEK, M. An objective method of sampling wheat fields to estimate production and quality of wheat. U. S. D. A. Tech. Bul. 814. 1942.
7. LEONARD, W. H., and CLARK, A. G. Field Plot Technique. Minneapolis: Burgess. 1939.
8. POWERS, LEROY. The nature of the series of environmental variances and the estimation of the genetic variances and the geometric means in crosses involving species of *Lycopersicon*. Genetics, 27:561–575. 1942.
9. SNEDECOR, G. W. Statistical Methods. Ames, Iowa: Iowa State College Press. 1940.
10. WINSOR, C. P., and CLARKE, G. L. A statistical study of variation in the catch of plankton nets. Sears Foundation: Jour. of Marine Res., 3, No. 1: 1–34. 1940.

IMPROVEMENT AND DISTRIBUTION OF SPRING-SOWN RED OATS[1]

F. A. COFFMAN, E. G. HEYNE, C. O. JOHNSTON, HARLAND STEVENS, AND H. C. MURPHY[2]

A NOTABLE change in varieties of oats has taken place during the past 25 years in the area in which spring-sown red oats are now grown (44).[3] This area, the transition zone between the fall-sown oat region in the South and the northern common white spring oat region, includes eastern Colorado, northern Texas, Oklahoma, Kansas, Missouri, parts of Arkansas, Kentucky, Tennessee and Virginia, and the southern parts of Nebraska, Illinois, Indiana, and Ohio. Some spring-sown red oats are grown in parts of West Virginia, Maryland, and New Jersey. California grows Kanota extensively, but largely from fall or winter seeding (24). Except in the Appalachian and Rocky Mountains, and the western deserts, these oats are now grown in a continuous belt across the central United States from the East to the West Coast. The culture of spring-sown red oats on such an extensive scale is a comparatively recent development in American agriculture. There are reasons for believing that the limits to which they may extend have not yet been reached. It is the purpose of this paper to present the history of the development of red oats in the area.

HISTORY

At the turn of the century, oat production in the above area was extremely hazardous as no really adapted varieties were available. Red Rustproof (also known as Red Texas), a midseason variety usually fall-sown, and the still less adapted common white oats

[1]Contribution from the Division of Cereal Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture, and the Idaho, Iowa, and Kansas agricultural experiment stations. Received for publication February 13, 1945.

[2]Senior Agronomist, Associate Agronomist, Pathologist, Associate Agronomist, and Pathologist, respectively, Division of Cereal Crops and Diseases. Acknowledgement is due the following individuals for data from the stations indicated: Gilbert H. Ahlgren and Robert S. Snell, Agricultural Experiment Station, New Brunswick, N. J.; R. O. Weibel, Agricultural Experiment Station, Morgantown, W. Va.; C. A. Lamb, Agricultural Experiment Station, Wooster, Ohio, for data from Columbus, Ohio; L. M. Josephson, Agricultural Experiment Station, Lexington, Ky.; G. H. Cutler, Agricultural Experiment Station, Lafayette, Ind.; Geo. H. Dungan, Agricultural Experiment Station, Urbana, Ill.; J. M. Poehlman, Agricultural Experiment Station, Columbia, Mo.; L. C. Burnett, Agricultural Experiment Station, Ames, Iowa; K. S. Quisenberry and Orrin J. Webster, Agricultural Experiment Station at Lincoln and North Platte, Nebraska; A. F. Swanson, Fort Hays Experiment Station, Hays, Kans.; C. B. Cross, Agricultural Experiment Station, Stillwater, Okla.; V. C. Hubbard, Southern Great Plains Field Station, Woodward, Okla.; I. M. Atkins, Substation No. 6, Denton, Tex.; J. F. Brandon, U. S. Dry Land Field Station, Akron, Colo.; and D. W. Robertson, Agricultural Experiment Station, Ft. Collins, Colo. Credit is also due T. R. Stanton, Senior Agronomist in Charge, and H. B. Humphrey, formerly Principal Pathologist In Oat Investigations, for interest and assistance in certain phases of the breeding project.

[3]Figures in parenthesis refer to "Literature Cited", p. 496.

from the Corn Belt and northward were about the only varieties to be had. It was not uncommon for northern-grown oats, shipped in for feed, to be used for seed, nor was it unusual for farmers to mow their oats for hay because they were worthless as a grain crop due to rust. Prior to 1900 oats in this region were among the least satisfactory of the crops then generally grown. Shortly after 1900, Burt, an early variety selected from a commercial field of Red Rustproof about 1878 in Tennessee (10) and also known as Early Ripe, Early June, etc., became of considerable importance in the area, but was not sufficiently satisfactory to become a predominant variety because of its variability.

Kherson was introduced into Nebraska in 1896 by the Nebraska Agricultural Experiment Station, and Sixty-Day, considered identical, was introduced from Russia by the U. S. Dept. of Agriculture in 1901 (54, 55). These varieties immediately became popular and were widely grown throughout the central portion of the country as far south as central Kansas and Missouri. Plant breeders, noting that these varieties were not entirely pure (11), made numerous selections and from their efforts Richland (2), Iogold (3), Iowar and Albion (4), State Pride (21), Nebraska 21 (19), Gopher (1), and other varieties resulted. Eventually these selections largely supplanted the parent varieties in most sections. Most notable of these selections was Richland (Iowa 105), a stem-rust resistant yellow oat distributed by the Iowa Agricultural Experiment Station in 1917. Another important selection, Gopher, a white oat, was distributed by the Minnesota Agricultural Experiment Station about 1920, but it was not grown in the spring-sown red oat area as it is somewhat later in maturing than Kherson. Even with these improvements none of the available varieties was well adapted in Kansas and Missouri. Red Rustproof and similar varieties were later than was desirable, had heavy hulls, numerous awns, were generally low in test weight per bushel, and, being late in maturity, were often damaged by rust and hot weather. Burt, although early, was so lacking in uniformity, it generally sold as mixed oats. Kherson and Sixty-Day and their selections, though relatively early-maturing, were not sufficiently so, and since they were lacking in heat and crown rust resistance, they were frequently seriously damaged by hot weather and rust. Richland lacked resistance to crown rust and was later than is considered desirable for conditions in the area.

In 1921 the Kansas Agricultural Experiment Station distributed about 600 bushels of pure seed of a strain of Fulghum named Kanota (37). Soon thereafter the growing of Kanota and other Fulghum strains from spring seeding spread rapidly. A survey of oat varieties grown in Kansas in 1925 indicated that 42% of the acreage was planted to Kanota. By 1930 Kanota had increased to some 90%[4] of the oat acreage of the state. The acreage of Fulghum-type oats expanded in a similar manner in other states and soon they became the leading oat varieties in Oklahoma, Missouri, and throughout the southern part of the Corn Belt.

[4]Estimate made by S. C. Salmon, formerly Professor of Farm Crops at Kansas State College.

Fulghum was selected by J. A. Fulghum of Warrenton, Ga., about 1892 (41, 42), being apparently an exceptionally early plant found in a field of Red Rustproof. The variety became popular for fall seeding in certain areas in the southeastern states about 1910 to 1912 but was not used nor tested extensively for spring seeding until after Kansas distributed Kanota. The manner in which Kanota came to be distributed is worthy of mention. The Kansas Agricultural Experiment Station[5] obtained some 20 to 30 lots of seed from many southern sources for seeding in the spring of 1916 in an attempt to find a more suitable variety than those then available. One of these was from the Robert Nicholson Seed Company, Dallas, Tex., designated as Nicholson Extra-Early Red Rustproof. This strain was outstandingly vigorous throughout the season and at harvest yielded at a rate of more than 100 bushels an acre, a very high yield for oats in Kansas at that time. It was so early and so outstandingly superior to all others in the nursery that it was immediately advanced to field plots, purified by roguing, and increased and distributed to farmers by the Kansas Experiment Station as noted above. It was first distributed as Kansas Fulghum but later as Kanota, partly because of uncertainty as to its identity with Fulghum but more especially to prevent the introduction of smut, known to be prevalent in oats in the South, which at that time was not prevalent in Kansas. Its acceptance by the farmers was immediate and as later results have shown, the recognition of its value for spring seeding marked the beginning of an epoch in oat production in the United States. Today, Fulghum and its selections and hybrid derivatives constitute one of the most valuable groups of oats in existence not only in America, but in several other parts of the world.

The gain to Kansas farmers brought about by the introduction and distribution of Kanota oats may be seen from Table 1, which gives the comparative yields, test weights, and dates of heading of Kanota as compared with representative varieties of the period. Most of the oats grown in Kansas at that time were Red Rustproof (Red Texas), with scattered acreages of Burt and various strains of Kherson and Sixty-Day. These extensive data show that Kanota averaged 9.4 bushels more than Red Texas, tested 4.2 pounds more per bushel, and was 5 days earlier in heading. It also exceeded Nebraska 21 (19), a representative white Kherson type oat, and Burt in yield and test weight and was as early in heading.

In Table 2 yields in the central United States of Kanota and Fulghum, together with certain more recently developed varieties, to be mentioned later, are compared with one or more of the principal varieties grown prior to the distribution of these two. The data include only those that have been published (6, 13, 14, 19, 20, 32, 33, 35, 36, 37, 39, 40, 57, 58). At most of these stations the yields of Kanota and Fulghum were superior to those of the varieties previously grown.

---

[5]Information obtained in letters received in October 1944 from R. P. Bledsoe and K. S. Quisenberry, formerly assistant professor of Farm Crops and formerly nursery foreman, respectively.

IMPROVEMENT OF SPRING-SOWN RED OATS BY SELECTION

Interest in breeding red oats was greatly stimulated by the introduction and distribution of Kanota and Fulghum (37, 39, 41). The need for early maturing varieties was more clearly recognized and the opportunities for improvement realized. It was soon noted that Kanota, Fulghum, and Burt were not pure and several stations from Ohio to Colorado began selecting from them (10, 12). Thousands of selections were made and tested, and several new varieties were produced and distributed. Colburt (6), a black-kerneled strain selected and distributed from Akron, Colo., in the early twenties, was probably the first pure-breeding Burt selection to be distributed. It was grown to some extent in Colorado and Nebraska but never became popular because of its black kernels and smut susceptibility. Among other Burt selections which are grown more extensively are Brunker and Trojan (20, 35, 36) selected at Akron, Colo., in 1919 and 1922, respectively, and Otoe (20), selected at Lincoln, Nebr., in 1920. As shown in Table 2, these Burt selections are more productive than Fulghum or Kanota in the drier sections and are equal to or superior to them as far east as Lincoln. Brunker, a very early-maturing, high-yielding, and smut-resistant oat, has become a leading variety on the high dry plains of eastern Colorado and similar areas in nearby states, including South Dakota (59). It yields well in more humid sections, such as in southern Illinois; but as it is subject to lodging, Brunker never has become an important variety east of the Great Plains. Trojan, a slender kerneled very early white oat, yields about the same as Brunker in Colorado and western Nebraska, but it lacks the quality of Brunker. It is somewhat resistant to smut and has exceptionally stiff straw. It is grown to a limited extent in eastern Colorado and western Nebraska. Otoe,

TABLE 1.—*Comparison of yields, test weights, dates of heading of Kanota with Red Texas (Red Rustproof), Nebraska 21, and Burt in Kansas.**

Variety	Period of test	Number of tests	Av. of variety	Kanota same tests	Deviation from Kanota
		Yield per Acre, Bushels			
Red Texas...	1916–32	268	31.6	41.0	−9.4
Burt........	1919–32	220	35.7	39.0	−3.3
Nebraska 21.	1921–32	182	33.7	40.1	−6.4
		Test Weight, Pounds per Bushel			
Red Texas...	1916–32	30	28.3	32.5	−4.2
Burt........	1919–32	23	31.2	32.0	−0.8
Nebraska 21.	1920–32	22	29.1	32.3	−3.2
		Date of Heading			
Red Texas...	1920–32	20	June 4	May 30	+5 days
Burt........	1920–32	21	May 31	May 31	±0 days
Nebraska 21.	1920–32	21	June 3	May 31	+3 days

*Data secured from tests at Manhattan and Hays and in cooperative experiments on Kansas farms, Kansas Agricultural Experiment Station.

a light-red oat, yields well in Nebraska, matures early, has stiff straw, and has some resistance to stem rust.

TABLE 2.—*Yields of Fulghum and Kanota oats and more recently selected spring-sown red oats compared with yields of varieties grown previously.*

Station and variety	Crop years included*	Yield per acre, bushels		
		Variety named	Check variety	Deviation from check
Ohio				
Wooster (Miami, check):				
Columbia	1933–37	52.0	45.6	+6.4
Franklin	1929–31	59.7	53.7	+6.0
Fulghum	1925–37	58.8	56.6	+2.2
Columbus (Miami, check):				
Columbia	1931–37	56.8	41.3	+5.5
Franklin	1927–37	51.9	44.5	+7.4
Fulghum	1927–31	48.0	47.2	+0.8
Illinois				
DeKalb Field (Sixty-Day, check):				
Brunker	1939–40	72.9	77.8	−4.9
Burt (C.I. 293)	1930–35	55.1	56.6	−1.5
Columbia	1932–41	59.4	59.1	+0.3
Franklin	1932–35	46.6	50.8	−4.2
Kanota	1924–31	71.6	66.9	+4.7
Texas Red	1917–19	68.5	72.1	−3.6
Urbana (Sixty-Day, check):				
Brunker	1930–39	60.9	59.7	+1.2
Burt (C.I. 293)	1930–37	62.6	60.5	+2.1
Columbia	1931–41	63.9	59.9	+4.0
Franklin	1932–36	55.1	55.4	−0.3
Kanota	1923–31	69.7	65.4	+4.3
Texas Red	1917–30	58.6	59.3	−0.7
Alhambra (Sixty-Day check):				
Brunker	1931–40	41.1	32.8	+8.3
Burt (C. I. 293)	1923–30	37.0	34.3	+2.7
Columbia	1931–41	38.1	33.3	+4.8
Franklin	1933–37	14.5	15.2	−0.7
Kanota	1922–31	26.8	31.8	−5.0
Texas Red	1919–22	18.8	24.5	−5.7
Indiana				
Lafayette (Gopher, check):				
Columbia	1932–38	61.9	57.2	+4.7
Franklin	1932–38	54.6	57.2	−2.6
Fulghum	1926–34	60.7	63.6	−2.9
Iowa†				
Ames (Richland, Iowa 105, check)				
Columbia	1937–42	65.7	62.6	+3.1
Kanota	1928–39	60.6	55.5	+5.1
Kanawha (Richland, Iowa 105, check):				
Columbia	1938–42	57.3	46.7	+10.6

TABLE 2.—*Concluded.*

Station and variety	Crop years included*	Yield per acre, bushels: Variety named	Check variety	Deviation from check
Missouri				
Columbia (Kherson, check):‡				
Burt (Mo. 015)	1919–30	48.3	46.3	+2.0
Columbia	1924–30	54.3	50.0	+4.3
Fulghum (Mo. 0124)	1919–30	49.3	46.3	+3.0
Texas Red (Mo. 0432)	1924–30	48.5	50.1	−1.6
Nebraska				
Lincoln (Kherson, check):				
Brunker	1931–39	48.7	40.7	+8.0
Burt (C.I. 293)	1931–37	42.4	40.8	+1.6
Columbia	1932–39	42.6	38.0	+4.6
Fulton	1938–39	48.2	40.4	+7.8
Kanota	1931–39	43.9	40.7	+3.2
Otoe	1931–39	47.8	40.7	+7.1
Trojan	1931–39	46.2	40.7	+5.5
Texas Red	1931–37	40.3	40.8	+0.5
North Platte (Kherson, check):				
Brunker	1931–39	29.1	24.7	+4.4
Burt (C.I. 293)	1931–39	29.9	24.7	+5.2
Columbia	1933–39	24.4	25.0	−0.6
Early Red Texas	1931–39	23.4	24.7	−1.3
Fulton	1938–39	29.5	17.7	+11.8
Kanota	1936–39	21.8	15.8	+6.0
Otoe	1938–39	21.9	17.7	+4.2
Trojan	1931–39	29.2	24.7	+4.5
Alliance (Kherson, check):				
Brunker	1932–39	26.1	22.7	+3.4
Burt (C.I. 293)	1931–37	18.9	17.0	+1.9
Fulton	1938–39	39.6	32.4	+7.2
Kanota	1931–39	23.0	20.8	+2.2
Otoe	1933–39	22.2	21.5	+0.7
Trojan	1931–39	25.6	20.8	+4.8
Colorado				
Akron (Kherson, check):				
Brunker	1923–35	26.0	20.3	+5.7
Colburt	1912–30	28.2	28.8	−0.6
Columbia	1932–35	20.9	17.0	+3.9
Kanota	1923–35	24.8	20.3	+4.5
Trojan	1929–35	21.4	16.3	+5.1

*Owing to various local conditions, yields were not always obtained every year during the period shown.

†Data are from two mimeographed reports: Burnett, L. C. Small grain information from experiments in progress. Agronomy Section, Farm Crops Subsection, Iowa Agr. Exp. Sta. Leaflet F. C. 10, 1939; Burnett, L. C., and Murphy, H. C. Small grain information for experiments in progress. Agronomy Section, Farm Crops Subsection, Iowa Agr. Exp. Sta. Leaflet F. C. 17, 1943.

‡Yield for the period 1919–23 is for Kherson (Mo. No. 040) and for the period 1924–30 for Kherson (Mo. No. 0955).

Selections from Fulghum include Franklin (43) selected at Columbus, Ohio, in 1922; Columbia (33, 40, 43) selected at Columbia, Mo., in 1920; and Frazier (47) a variety of the Fulghum type, selected at Denton, Tex., in 1918 from a variety known as Frazier Red Rust-

proof. Franklin, though productive and resistant to lodging, has proved to be very susceptible to smut, and as its yield is less than that of Columbia (Table 2) it has rapidly lost favor and is not widely grown.

Columbia originated as an "off-type" plant in Fulghum and often is termed "Burt-like" in appearance. It is tall, but has stiff straw, is early maturing, has a high test weight under favorable conditions, and has some smut resistance. The kernels are small and gray. Lacking the cold requirement of Kanota and Fulghum (39, 52), it yields better than these varieties from late seeding. Because of these various desirable qualities, Columbia by 1940 had become not only the leading spring-sown red oat in the United States, but also one of the most widely grown of all spring oat varieties in the country. It has proved especially popular in Missouri and in the southern Corn Belt as far west as the Missouri River.

Frazier, similar to Kanota and Fulghum in most plant and kernel characters, is an early, vigorous, awned, plump-kerneled, short-strawed red oat which was distributed from Denton, Tex. It is grown to a limited extent in northern Texas and in Oklahoma.

BREEDING FOR DISEASE RESISTANCE

BREEDING FOR RESISTANCE TO SMUT

One reason the Kanota oat became so popular and spread so rapidly was its resistance to the smut then prevailing in Kansas (37). However, in 1925, a collection of smut obtained from southeastern Kansas in 1924 infected Kanota up to 14%. In 1925, and again in 1926, considerable smut was observed in Fulghum throughout the area south and east of Kansas where the variety was being grown both from fall and spring seeding. By that time it was clear that a race of smut to which the Fulghum-type oats were susceptible was present in many widely scattered areas over the country (34). Furthermore, it was soon evident that Fulghum and Kanota were extremely susceptible to both crown rust and stem rust. As a result, a hybridization program was started in 1926, using as parents Fulghum or Kanota and such disease-resistant varieties as were then available, including Markton for smut resistance, Richland for stem rust resistance (22, 23), and certain Green Russian strains (9, 23, 25) for crown rust resistance. Nothing of value for this area evolved from the Green Russian crosses because of the late maturity of the segregates. A few promising strains resulted from the Richland crosses, but the Fulghum × Markton crosses proved the most productive. From one of these, Fulton was obtained and distributed to Kansas farmers in 1939 (15, 43). Its desirable characteristics include high yield, earliness, resistance to most races of smut, and good test weight.

The superiority of Fulton in these respects when grown in Kansas is shown by the data presented in Table 3 for the period from 1931 to 1943, inclusive. The data on smut infection are for plants grown from seed artificially inoculated with smut collected in Kansas only. It will be seen that Fulton had an average of 0.6% of smutted pani-

cles as compared with 36.8% in Kanota. In the uniform smut nurseries (49) grown for a total of 90 station years during the period 1937 to 1943, inclusive, only 1.4% of Fulton plants were smutted as compared with 12.9% for Fulghum. In these nurseries the inoculum for each nursery used was collected in the area in which it was grown. As shown in Table 3, Fulton outyielded Kanota by an average of 4.8 bushels, averaged 1.8 pounds higher in test weight, and was 3 days earlier. In the coordinated yield-test nurseries grown cooperatively by experiment stations in different states and by the U. S. Dept. of Agriculture, representing about 50 station years, Fulton outyielded Kanota and Fulghum by more than 20%.

BREEDING FOR RESISTANCE TO CROWN RUST AND SMUT

Greatly enlarged opportunities in breeding for crown-rust resistance were afforded by the observation at Manhattan, Kans., and Ames, Iowa, in 1929 (26, 28) of the resistance of the South American variety Victoria, which had been introduced from South America by the U. S. Dept. of Agriculture in 1927. It was later found to be resistant to smut also (30, 31, 53). It was crossed with Red Rustproof the same year its resistance was discovered by taking advantage of the later maturity of plantings made at Aberdeen, Idaho. In the spring of 1930 Victoria was crossed with Richland, Fulghum, Nortex, Kanota, and Trojan, and in later years with many other varieties.

TABLE 3.—*Comparative yield, test weight, date of first heading, and smut infection of Fulton and Kanota in Kansas 1931–43.**

Item	No. of tests	Fulton	Kanota
Yield per acre, bu.	133	49.0	44.2
Test weight, per bu.	40	29.5	27.7
Date first heading	23	May 23	May 26
Smut infection, %	13	0.6	36.8

*Data secured from Agronomy and Botany Departments, and cooperative experiments on farms Kansas Agricultural Experiment Station, Manhattan, Kans.

Of the early hybrids, the Victoria-Richland cross has been by far the most important and a number of selections from it have been named and distributed and are widely grown by Corn Belt farmers (27, 30, 38, 42, 43, 45, 50, 51). Among these are Boone, Control, and Tama distributed by the Iowa Experiment Station; Vicland by the Wisconsin Experiment Station; Vikota by the South Dakota Experiment Station; and Cedar by the Nebraska and Iowa Experiment stations. The production of these varieties constitutes one of the most important contributions of plant breeders in history. They are best adapted, however, to the Corn Belt proper, being generally somewhat later in maturity than is desirable in oats for the area under consideration here, however, they are grown in the area to some extent.

One variety, Fultex (7, 8, 30, 43, 46), was obtained from the Fulghum × Victoria cross (8) and distributed by the Texas Experiment Station in 1940. It is a short, stiff-strawed variety, resistant

to smut and crown rust and is adapted to spring sowing primarily in northern Texas where a type suitable for combining is desired. It is too late for growing extensively farther north. Fultex is also grown to some extent from fall seeding in Texas. Additional promising varieties for fall seeding also have been obtained from some of the other Victoria crosses (7, 8, 30, 31, 43, 46).

Another important contribution to oat improvement was made by the discovery of the crown rust resistance of Bond at Ames, Iowa, in 1931 (25, 27, 29, 30, 48). Numerous crosses were made with Bond in 1932 (16, 17, 27, 29, 30, 53), but to date none of the progeny of these has proved especially promising for the spring-sown red oat area primarily because few segregates have proved sufficiently early and because Bond and segregates from its crosses so far have lacked resistance to several of the "red-oat races" of smut. However, one selection, Camellia, from a Bond × Alber cross has been distributed for fall seeding in Louisiana (46).

BREEDING FOR RESISTANCE TO CROWN AND STEM RUSTS AND SMUT

Recognition of the need for combining in a single variety early maturity and resistance to both rusts and to the various races of smuts constituted another important step. This need was thoroughly demonstrated in 1935 when the most severe crown rust epidemic in years occurred in Kansas. All strains in the nursery were destroyed early in the season except those having resistance to crown rust and these were killed later by stem rust. Crosses designed to combine resistance to all these diseases in early-maturing varieties were made that same summer at Aberdeen, Idaho, again making use of the later maturity of oats at that station. The F_1 generation of these crosses was grown in the greenhouse at Arlington, Va., in 1935–36, where they were inoculated with smut and the rusts (18). The subsequent early generations were grown principally at Aberdeen, Idaho, and Ames, Iowa, with plantings during the winter in the greenhouse at Arlington, Va. In 1938, the breeding work at Manhattan, Kans., was considerably expanded and an overhead sprinkler system was installed to aid in creating artificially induced rust epidemics. During the period of 1937 to 1939, bulked seed and panicle selections from these crosses were distributed to a number of cooperating stations, several thousand selections being grown at Manhattan, Kans., Ames, Iowa, Aberdeen, Idaho, Lincoln, Nebr., Columbia, Mo., Columbus, Ohio, Akron, Colo., and elsewhere. An important feature of this program has been the use of greenhouses in early generations, together with seedings at Aberdeen where oats may be sown as late as mid-May. This has permitted the growing of two generations each year. This procedure, combined with the use of artificially induced epidemics both in the greenhouse and field, assisted by overhead irrigation as at Manhattan, has greatly speeded up the breeding program and greatly increased its efficiency by eliminating disease-susceptible segregates in early generations.

Four of the more promising strains derived from these crosses are of special interest. Two of these, Ventura and Osage, originated as "sister selections" from the F_8 progeny of a Victoria-Richland × Ful-

ton cross. These strains were selected in 1939 on the basis of observations made and data obtained in 1939 and in previous years at Manhattan, Kans., Ames, Iowa, Aberdeen, Idaho, and Arlington, Va., and are considered the joint products of these stations. Neosho and C. I. 4140 also resulted from this cooperation, although final selections were made at Manhattan in 1939. Each was obtained from a different cross, using different strains from Markton × Fulghum hybrids as parents and crossing them on Victoria × Richland segregates.

All four strains have the resistance of their Victoria × Richland parents to the ordinary races of crown and stem rust but lack resistance to races 8 and 10 of stem rust. Neosho and C. I. 4140 are resistant to the smut race that attacks Fulton; whereas Osage and Ventura are somewhat susceptible, although as shown by Hansing, *et al.* (15), no more susceptible to that race than Fulton itself. Except that these varieties lack resistance to this smut race all four combine rather satisfactorily the disease resistance, yielding ability, quality, and earliness of their parents.

In plant characters, Osage and Ventura both tiller exceptionally well, have short straw, and resemble Fulghum slightly in general appearances. Their kernels are yellow to very light reddish yellow in color and are usually awnless, bearing a resemblance to the Victoria-Richland varieties previously mentioned.

Although as early as Ventura and Osage, C. I. 4140 is the tallest of the four. It resembles Fulton more closely in general appearance, has rather large panicles, and produces light yellowish-red awnless kernels. Neosho is characterized in early growth by its exceptionally dark green, very erect-growing leaves. It makes a rapid initial growth in early spring but does not tiller so profusely as the other three. It has exceptionally stiff straw, the panicles are small, resembling Boone in appearance, and the kernels are light red, occasionally awned, and basal hairs usually are present. It more nearly resembles the Fulghum oat in kernel characters than does Osage or Ventura.

These four new varieties, among others, were included in the Uniform Spring-sown Red Oat Nurseries in 1942 and in additional nurseries in 1943 and 1944. Yields, test weight, date of first heading, height of plant, percentage of lodging and infection by crown rust, smut, and leaf-spot diseases are given in Tables 4, 5, and 6, together with comparable data for Fulton, Kanota, and Columbia. The yield data are averaged for the stations west and south of Iowa (20 station years) and for the remaining seven stations to the east and north of Columbia, Mo. (14 station years). Averages are given also for all station years.

All four of the new varieties outyielded the best of the old varieties as an average for all station years in both the southwestern and south-central divisions. At a few stations this was not the case. At Woodward, Okla., in 1942, Fulton outyielded all others by a wide margin, presumably because of its earliness. At Columbus, Ohio, Morgantown, W. Va., New Brunswick, N. J., and Columbia, Mo., Columbia outyielded the new varieties in 1942. Rust was not a factor in any of these tests.

The new varieties, it will be noted, are slightly later than Fulton but are as early as Kanota and their test weights average about the same as Columbia. The straw averages shorter than Columbia and lodging for all of them is distinctly less than in any of the older varieties.

The new varieties are not immune from crown rust or stem rust, as these data show, but they are highly resistant to the prevailing races as compared with Fulton, Kanota, and Columbia. The effect of the combined infections of crown and stem rust on these new varieties as compared with rust on old susceptible varieties is shown in Fig. 1. All are resistant to the races of smut which attack Fulghum,

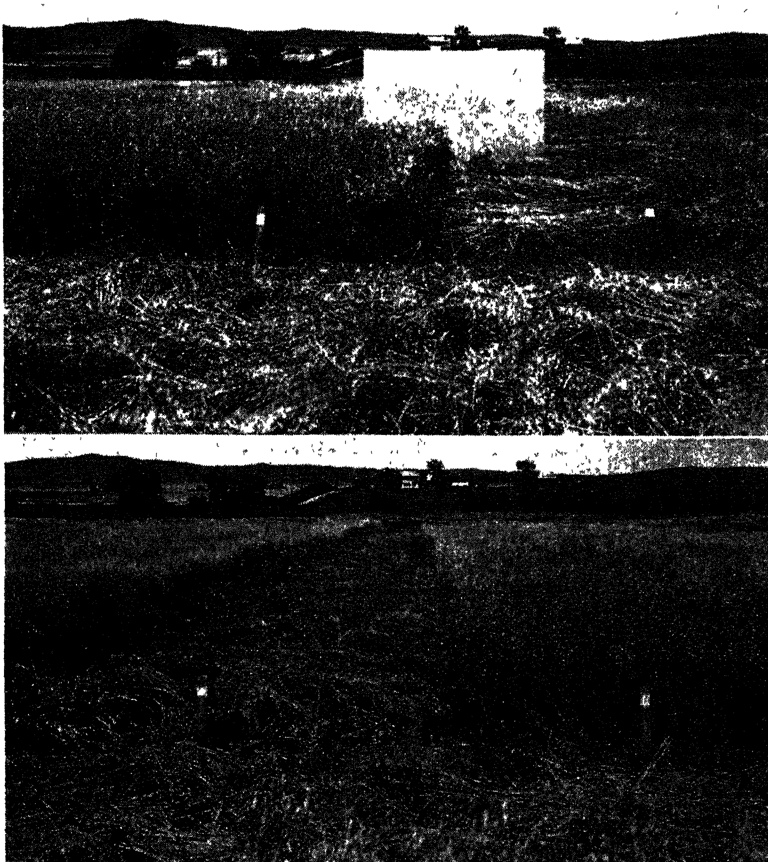

FIG. 1.—Field plots of the new rust-resistant oats and old varieties which lack rust resistance at Manhattan, Kans., 1943. *Upper left*, Ventura, 58.9 bushels; *upper right*, Fulton, 27.1 bushels; *lower left*, Kanota, 32.9 bushels; *lower right*, Neosho, 56.4 bushels. The susceptible varieties (top right and bottom left) were so badly damaged by rust that they lodged 100% before maturity while the resistant varieties stood until harvested.

TABLE 4.—*Yield in bushels per acre of four new and three standard oat varieties included in the Uniform Spring-Sown Red Oat Nurseries in 1942, 1943, and 1944.*

Year and station	Variety and C. I. Nos.						
	Ventura C. I. 3989	Osage C. I. 3991	Neosho C. I. 4141	C. I. 4140	Fulton C. I. 3327	Kanota C. I. 839	Columbia C. I. 2820
				Southwest Area			
1942:							
Lincoln, Nebr.	74.2	71.2	65.2	74.7	68.7	61.5	73.3
North Platte, Nebr.	68.9	77.3	73.6	71.5	68.0	68.6	60.1
Columbia, Mo.	53.8	49.7	53.1	56.5	59.6	44.2	63.3
Manhattan, Kans.	46.0	47.3	62.5	52.2	45.5	39.1	46.1
Hays, Kans.	44.6	34.6	49.4	37.4	51.8	33.2	39.0
Woodward, Okla.	18.5	12.0	5.7	12.5	25.7	19.8	5.1
Akron, Colo.	54.1	53.9	53.2	42.0	48.0	43.1	35.1
Average	51.4	49.4	51.8	49.5	52.5	44.2	46.0
1943:							
Lincoln, Nebr.	69.4	75.8	65.8	84.4	55.1	48.9	58.2
Columbia, Mo.	33.7	30.6	31.6	34.0	27.9	30.3	36.1
Manhattan, Kans.	82.9	84.5	67.9	63.8	42.1	43.5	47.8
Hays, Kans.	18.8	20.4	28.6	21.8	40.2	26.0	26.2
Stillwater, Okla.	41.0	43.1	38.8	40.0	29.2	30.0	28.6
Denton, Texas	59.7	67.8	62.8	64.0	56.8	49.0	58.3
Akron, Colo.	23.8	20.0	25.6	25.7	24.4	18.8	18.3
Average	47.0	48.9	45.9	47.7	39.4	35.2	39.1
1944:							
Lincoln, Nebr.	42.0	41.3	30.1	41.7	27.5	28.3	35.0
Columbia, Mo.	27.9	27.5	32.2	34.9	34.9	23.1	34.1
Manhattan, Kans.	52.0	52.1	50.3	57.5	42.8	37.9	37.4
Hays, Kans.	30.6	50.8	46.4	52.0	44.0	52.0	50.4
Stillwater, Okla.	41.2	36.6	41.6	39.3	37.5	35.0	32.5
Akron, Colo.	51.4	37.6	38.9	45.2	44.7	29.4	41.9
Average	40.9	41.0	39.9	45.1	38.6	34.3	38.6
Av. for all 20 station years	46.7	46.7	46.2	47.6	43.7	38.1	41.3

Corn Belt and East

1942:							
New Brunswick, N. J.	36.6	35.3	38.0	35.7	44.5	42.6	42.7
Morgantown, W. Va.	54.6	50.8	62.6	59.8	66.9	54.6	72.9
Columbus, Ohio	45.6	67.5	66.4	65.1	44.5	46.4	67.6
Lafayette, Ind.	65.6	66.6	77.5	66.4	63.8	49.7	61.9
Urbana, Ill.	71.1	79.1	69.5	57.3	61.0	62.2	57.3
Ames, Iowa	75.3	69.7	77.0	66.7	42.7	47.0	46.7
Average	58.1	61.5	65.2	58.5	53.9	50.4	58.2
1943:							
New Brunswick, N. J.	43.0	38.6	41.0	46.0	48.4	37.6	49.6
Urbana, Ill.	51.7	51.3	54.6	51.1	54.9	42.0	57.0
Ames, Iowa	68.5	72.3	61.6	54.2	34.7	29.0	38.5
Average	54.4	54.1	52.4	50.4	46.0	36.2	48.4
1944:							
New Brunswick, N. J.	57.3	49.8	49.7	53.7	58.7	62.2	51.4
Columbus, Ohio	52.1	53.9	56.4	60.5	66.5	49.3	73.8
Lexington, Ky.	39.8	41.8	42.7	42.3	42.2	40.5	41.5
Lafayette, Ind.	52.3	71.5	57.0	60.0	62.1	38.6	53.3
Ames, Iowa	60.7	61.4	44.1	45.4	38.8	19.0	39.0
Average	52.4	55.7	50.0	52.4	53.7	41.9	51.8
Av. for all 14 station years	55.3	57.8	57.0	54.6	52.1	44.3	53.8
Av. for 34 station years both areas	50.2	51.3	50.6	50.5	47.2	40.7	46.5
Increase over Kanota:							
Bushels	+9.5	+10.6	+9.9	+9.8	+6.5	—	+5.8
Per cent	+23.3	+26.0	+24.3	+24.1	+16.0	—	+14.3

TABLE 5.—*Test weight, date of heading, height of plant, and percentage of lodging of four new and three standard varieties grown in the cooperative Uniform Spring-Sown Red Oat Experiment in 1942, 1943, and 1944.*

Year and number of stations	Variety and C. I. Nos.						
	Ventura C.I. 3989	Osage C. I. 3991	Neosho C. I. 4141	C. I. 4140	Fulton C. I. 3327	Kanota C. I. 839	Columbia C. I. 2820
	Weight per Bushel, Lbs.						
1942 (6 stations)	30.5	31.7	32.6	31.7	31.5	30.5	32.1
1943 (6 stations)	29.0	29.6	30.3	29.7	28.5	27.6	29.2
1944 (9 stations)	30.4	29.6	30.8	30.2	30.1	28.1	30.4
Av., 21 stations	30.0	30.2	31.2	30.5	30.0	28.6	30.5
	Date of First Heading, June						
1942 (11 stations).......	5	6	8	6	2	7	5
1943 (8 stations)	5	5	8	5	2	4	13
1944 (8 stations)	12	12	13	12	9	15	12
Av., 27 stations	8	8	10	8	5	9	10
	Height of Plants, Inches						
1942 (12 stations)......	29.3	29.0	29.3	30.8	33.3	34.3	33.9
1943 (8 stations)	27.8	28.6	28.9	29.8	31.7	31.4	33.8
1944 (9 stations)	25.2	25.4	25.9	27.3	28.4	28.4	30.0
Av., 29 stations	27.6	27.8	28.1	29.4	31.4	31.7	32.7
	Lodging of Straw, %						
1942 (5 stations)	16.8	13.4	14.0	19.4	29.4	39.0	31.0
1943 (6 stations)	12.7	8.7	8.5	9.6	32.3	25.2	36.0
1944 (3 stations)	20.3	20.0	6.7	23.3	42.7	29.0	46.3
Av., 14 stations	15.8	12.8	10.1	16.0	33.5	30.9	36.4

but none equals Kanota in freedom from injury from leaf spot diseases, including halo blight.

Ventura and Osage were produced for the spring-sown red oat area as described above. Preliminary tests, however, indicate they compare very favorably in yield with Tama, Vicland, Boone, Marion, etc., to the north of this area. Further tests seem desirable.

Small increase seedings of Osage and Ventura were made at Aberdeen in 1942 and again in 1943. The exceptional promise of Ventura, one of these four varieties, was first recognized by the California Experiment Station in 1942. ~~It was increased~~ there in 1943 and was distributed in a limited way by the California Experiment Station that fall and made a favorable showing in 1944. All four varieties were increased in Kansas in 1943 and 1944, and Osage and Neosho will be distributed in Kansas in 1945. Osage was increased in Florida in 1943–44. Considerable seed of several of these varieties will be available for distribution in the spring of 1946.

TABLE 6.—*Reaction of four new and three standatd varieties to rust and smut in the cooperative Uniform Spring-Sown Red Oat Experiment in 1942, 1943, and 1944.*

Station	Year	Variety and C. I. Nos.						
		Ventura C. I. 3989	Osage C. I. 3991	Neosho C. I. 4141	C. I. 4140	Fulton C. I. 3327	Kanota C. I. 839	Columbia C. I. 2820
Infection by Crown Rust (Coefficient of Infection)								
Manhattan, Kans...	1944	15.0	12.0	20.0	20.0	53.0	55.0	55.0
Columbia, Mo......	1942	1.5	1.5	1.5	3.0	56.0	80.0	56.0
Columbia, Mo.....	1943	1.5	1.5	1.5	1.5	64.0	80.0	64.0
Ames, Iowa.........	1942	4.0	4.0	5.0	10.0	39.0	57.0	48.0
Ames, Iowa.........	1943	5.0	2.0	10.0	27.0	43.0	55.0	51.0
Ames, Iowa.........	1944	1.0	1.0	4.0	4.0	46.0	49.0	50.0
Average............		4.7	3.7	7.0	9.2	50.2	62.7	54.0
Infection by Stem Rust (Coefficient of Infection—Races 2 and 5)								
Manhattan, Kans...	1944	2.0	6.0	9.0	6.0	39.0	30.0	35.0
Ames, Iowa.........	1942	0.0	0.0	0.0	0.0	35.0	37.0	42.0
Ames, Iowa.........	1943	1.0	1.0	11.0	2.0	37.0	35.0	44.0
Ames, Iowa*........	1944	20.0	20.0	20.0	25.0	32.0	35.0	55.0
Average............		5.8	6.8	10.0	8.3	35.8	34.3	44.0
Infection by smut (from Fulghum-type Oats, %)†								
Manhattan, Kans...	1942	0	0	0	0	T‡	93.0	1.0
Manhattan, Kans...	1943	0	0	0	0	T	68.0	0.0
Manhattan, Kans...	1944	0	0	0	0	0	19.0	T
Average............		0	0	0	0	T	60.0	T
Infection by Leaf Spot Diseases, Including Halo Blight, %								
Ames, Iowa.........	1942	4.0	9.0	2.0	2.0	2.0	T	7.0
Ames, Iowa.........	1943	4.0	5.0	10.0	5.0	6.0	3.0	6.0
Ames, Iowa.........	1944	8.0	8.0	10.0	11.0	10.0	3.0	9.0
Average............		5.3	7.3	7.3	6.0	6.0	2.0	7.3

*Some stem rust races 8 and 10 present.
†Smut data supplied by Hansing (15).
‡T = Trace.

There obviously is still an opportunity and need for further improvement of spring-sown red oats. Columbia, which is the most widely grown red oat between the Appalachians and the Missouri River, although often injured by rust, undoubtedly has valuable characteristics that should be used. In 1937 Columbia was crossed with disease-resistant segregates from the Victoria × Richland cross in an attempt to remedy the disease susceptibility of an otherwise good type of oat. Progeny of these crosses have been grown and selected largely at Ames, Iowa, Manhattan, Kans., and Aberdeen, Idaho, making use of the breeding methods previously discussed. Some of them have been grown in field plots and in the Uniform Regional Nurseries. Most of them are somewhat later maturing

than Columbia and certainly later than is desirable for the area west of the Missouri River. East of the Missouri River several, notably C. I. 4152 and 4153, which have been grown in more than 10 comparable tests have exceeded Columbia in yield by as much as 10% or more. Also, they have equalled or exceeded Columbia in weight per bushel, have lodged far less than Columbia in the same tests, and have been very much less infected by crown rust, stem rust, and by smut. Some of the selections from these crosses may eventually prove valuable for the Corn Belt.

BREEDING FOR RESISTANCE TO NEWLY THREATENING RACES OF RUST

Recent observations indicate that some rust races previously thought to be of rather infrequent occurrence are increasing in the area where spring-sown red oats are adapted. Probably the more important of these races are stem rust races 8 and 10 (22, 23, 56) and crown rust race 45. These observations have prompted the making of additional crosses in an attempt to incorporate resistance to all races into oats adapted in the area insofar as possible.

Two unnamed oat varieties, C. I. 3644 and 3842, derived from crosses between Bond and Anthony (16, 17) and Iowa D69 (Richland × Green Russian) and Bond (29), respectively, were found to have resistance to stem rust races 8 and 10 (30, 56). At Aberdeen, Idaho, in 1939 the writers crossed the above varieties with one of the more promising selections from the Fulghum-Markton × Victoria-Richland crosses previously discussed. Later, in 1939–40, an Anthony × Bond selection was crossed with a Richland × Fulghum selection at Manhattan, Kans. (5). Progeny from these crosses have been secured which are resistant to stem rust races 8 and 10 as well as to the ordinary races of stem rust and of crown rust. Some of these progenies appear to be promising in other respects. Certain of these have the "Bond type" of crown-rust resistance which is superior to the Victoria type (27). Further, additional resistance to smut, to crown rust, and to the stem rust races 8 and 10, as well as the common races of crown rust and stem rust, has now been combined in crosses involving the new oat Ventura. There are reasons for believing that some of the segregates of these latest crosses will prove valuable.

SUMMARY AND CONCLUSIONS

The spring-sown red oat region extends from coast to coast across the central portion of the United States, exclusive of the Rocky and Appalachian Mountains and western desert areas. It includes the southern Corn Belt and southward to the Cotton Belt, overlaping the fall-sown oat area on the south and the spring-sown white oat area on the north. Within this belt other types of oats are largely grown only in the Appalachian and in the Rocky Mountain areas. The spring-sown red oat area produces 20 to 25% of the oats grown in the United States. Fifty years ago Red Rustproof, Burt, and white oats from the north were the principal varieties. They were very poorly adapted and failures were frequent.

Interest in red oats for spring seeding was greatly stimulated by

the distribution of Kanota oats by the Kansas Experiment Station in 1921. Previous to this Fulghum and its derivatives had been grown exclusively from fall seeding. Following the distribution of Kanota, the acreage of spring-sown red oats greatly expanded and Fulghum and Kanota eventually were grown extensively throughout the area. Selection of improved strains of Fulghum, Burt, and Red Rustproof resulted in the distribution of Frazier selected at Denton, Tex., in 1918, Brunker and Trojan at Akron, Colo., in 1919 and 1922, respectively; Otoe at Lincoln, Nebr., in 1920; Columbia at Columbia, Mo.; and Franklin at Columbus, Ohio, in 1922. By 1940 Columbia had become one of the leading oat varieties in the central United States.

The need for rust- and smut-resistant oats in the area had long been recognized and a cooperative hybridization program was started in 1926 to breed oats of the Fulghum type that would be resistant to smuts, crown rust, and stem rust. From crosses made at that time the smut-resistant variety, Fulton, was developed and distributed to farmers of Kansas in 1939.

In 1929, the exceptional crown rust resistance of the South American variety Victoria was first observed in the United States at Manhattan, Kans., and later confirmed at Ames, Iowa. It was crossed with Red Rustproof that year by taking advantage of the later maturity of oats at Aberdeen, Idaho, and later, with many other varieties. From a Victoria × Richland cross have come the disease-resistant, early-maturing varieties Boone, Cedar, Control, Tama, Vicland, and Vikota which are being extensively grown in the Corn Belt proper and somewhat in the spring-sown red oat area. Fultex, a short, stiff-strawed, combine type derived from a Victoria × Fulghum cross, is grown to a limited extent in northern Texas but is too late for seeding farther north.

In 1931, the unusual crown rust resistance of the Bond variety was discovered at Ames, Iowa, and numerous crosses with it were made in 1932 and later, but so far no selections have proved especially promising for the red-oat area.

In 1935 the more promising selections then available in Kansas were crossed with crown and stem rust resistant segregates from the Victoria × Richland cross. The selected progeny of these crosses include a number of very promising, early maturing, crown rust, stem rust, and smut-resistant varieties, which have yielded well not only in the area here described but also in the area farther north. One of these, Ventura, has been distributed in California. Osage and Neosho have been increased and will be distributed in Kansas in 1945.

Crosses have been made to add crown and stem rust resistance to the otherwise very desirable variety Columbia and to combine in desirable varieties the resistance to crown rust race 45 and stem rust races 8 and 10. Promising selections from these crosses have been made.

As a result of this oat breeding program, started some 25 years ago, varieties now are available for the spring-sown red oat area which are highly productive, early maturing, reasonably satisfactory

as to plant and grain characters, and which have resistance to all the more common races of crown rust, stem rust, and the smuts. These varieties do not, however, have as tall nor as stiff straw as is desired, their bushel weight could be increased, and they are known to lack resistance to some of the new and threatening races of crown rust, stem rust, and smut. Present efforts of the breeding program are being focused on correcting each of these deficiencies and indications are that a reasonable degree of success may be expected.

LITERATURE CITED

1. ARNY, A. C., and HAYES, H. K. Recommended varieties of farm crops for Minnesota. Minn. Agr. Exp. Sta. Bul. 226. 1925.
2. BURNETT, L. C. Improving the oat crop. Iowa Agr. Exp. Sta. Bul. 175. 1918.
3. ———. Iogold Oats. Iowa Agr. Exp. Sta. Bul. 247. 1928.
4. ———, STANTON, T. R., and WARBURTON, C. W. Improved oat varieties for the Corn Belt. U. S. D. A. Bul. 1343. 1925.
5. COCHRAN, GEORGE W., JOHNSTON, C. O., HEYNE, E. G., and HANSING, E. D. Inheritance of reaction to smut, stem rust and crown rust in four red oat crosses. Jour. Agr. Res., 70:43–61. 1945.
6. COFFMAN, FRANKLIN A. Experiments with cereals at the Akron (Colo.) Field Station in the 15-year period, 1908–1922, inclusive. U. S. D. A. Bul. 1287. 1925.
7. ———. Survival of oats grown in winterhardiness nurseries, 1937 to 1941. Jour. Amer. Soc. Agron., 34:651–658. 1942.
8. ———, HUMPHREY, H. B., and MURPHY, H. C. New red oats for fall seeding resistant to rusts and smuts. Jour. Amer. Soc. Agron., 33:872–882. 1941.
9. ———, MURPHY, H. C., STANTON, T. R., BURNETT, L. C., and HUMPHREY, H. B. New smut and rust resistant oats from Markton crosses. Jour. Amer. Soc. Agron., 30:797–815. 1938.
10. ———, PARKER, JOHN H., and QUISENBERRY, KARL S. A study of variability in the Burt oat. Jour. Agr. Res., 30:1–64. 1925.
11. ———, and STANTON, T. R. Variation in the Kherson oat at Akron, Colorado. Jour. Agr. Res., 30:1063–1082. 1925.
12. ———, and TAYLOR, J. W. Widespread occurrence and origin of fatuoids in Fulghum oats. Jour. Agr. Res., 52:123–131. 1936.
13. DUNGAN, G. H., and BURLISON, W. L. Varieties of oats for Illinois. Ill. Agr. Exp. Sta. Bul. 339. 1929.
14. ———, BONNETT, O. T., and BURLISON, W. L. Spring oat varieties for Illinois. Ill. Agr. Exp. Sta. Bul. 481. 1942.
15. HANSING, E. D., HEYNE, E. G., and MELCHERS, L. E. Smut resistant oats for Kansas. Jour. Amer. Soc. Agron., 37:499–508. 1945.
16. HAYES, H. K. Breeding for resistance to crown rust, stem rust, smut, and desirable agronomic characters in crosses between Bond, *Avena byzantina* and cultivated varieties of *Avena sativa*. Jour. Amer. Soc. Agron., 33:164–173. 1941.
17. ———, MOORE, M. B., and STAKMAN, E. C. Studies of inheritance in crosses between Bond, *Avena byzantina*, and varieties of *A. sativa*. Minn. Agr. Exp. Sta. Tech. Bul. 137. 1939.
18. HUMPHREY, H. B., and COFFMAN, F. A. A study of the reaction of F_1 oat hybrids and their respective parental lines to inoculation with smuts and rusts. Phytopath., 27:183–189. 1937.
19. KIESSELBACH, T. A., and RATCLIFF, J. A. Oats Investigations. Nebr. Agr. Exp. Sta. Bul. 160. 1917.
20. ———, WEBSTER, O. J., and QUISENBERRY, K. S. Varieties of oats, barley, and spring wheat in Nebraska. Nebr. Agr. Exp. Sta. Bul. 328. 1940.
21. LEITH, B. D., and DELWICHE, E. J. Wisconsin oats. Wis. Agr. Exp. Sta. Bul. 340. 1922.

22. LEVINE, M. N., and SMITH, D. C. Comparative reaction of oat varieties in the seedling and mature stages to physiologic races of *Puccinia graminis avenae*, and the distribution of these races in the United States. Jour. Agr. Res., 55:713–729. 1937.
23. ————, STAKMAN, E. C., and STANTON, T. R. Field Studies on the rust resistance of oat varieties. U. S. D. A. Tech. Bul. 143. 1930.
24. MACKIE, W. W. Oat varieties in California. Calif. Agr. Exp. Sta. Bul. 467. 1929.
25. MURPHY, H. C. Physiologic specialization in *Puccinia coronata avenae*. U. S. D. A. Tech. Bul. 433. 1935.
26. ————. Reaction of the Victoria oat variety to crown rust. Phytopath. 26:396–397. 1936.
27. ————, BURNETT, L. C., KINGSOLVER, C. H., STANTON, T. R., and COFFMAN, F. A. Relation of crown-rust infection to yield, test weight, and lodging of oats. Phytopath., 30:808–819. 1940.
28. ————, and STANTON, T. R. Oat varieties highly resistant to crown rust. Jour. Amer. Soc. Agron., 22:573–574. 1930.
29. ————, ————, and COFFMAN, F. A. Hybrid selections of oats resistant to smuts and rusts. Jour. Amer. Soc. Agron., 28:370–373. 1936.
30. ————, ————, ————. Breeding for disease-resistance in oats. Jour. Amer. Soc. Agron., 34:72–89. 1942.
31. ————, ————, and STEVENS, HARLAND. Breeding winter oats resistant to crown rust, smut, and cold. Jour. Amer. Soc. Agron., 29:622–637. 1937.
32. OHIO AGR. EXP. STATION. Handbook of experiments in agronomy. Ohio Agr. Exp. Sta. Spec. Circ. 53. 1938.
33. POEHLMAN, J. M. Growing good crops of oats in Missouri. Mo. Agr. Exp. Sta. Bul. 439. 1942.
34. REED, GEORGE M., and STANTON, T. R. Reaction of oat varieties to physiologic races of loose and covered smuts of red oats. Jour. Agr. Res., 52:1–15. 1936.
35. ROBERTSON, D. W., KEZER, ALVIN, COFFMAN, F. A., BRANDON, J. F., KOONCE, DWIGHT, and DEMING, G. W. Oat varieties in Colorado. Colo. Agr. Exp. Sta. Bul. 370. 1930.
36. ————, KOONCE, DWIGHT, CURTIS, J. J., and BRANDON, J. F. Oat production in Colorado, 1928–1935. Colo. Agr. Exp. Sta. Bul. 430. 1936.
37. SALMON, S. C., and PARKER, JOHN H. Kanota: An early oat for Kansas. Kans. Agr. Exp. Sta. Circ. 91. 1921.
38. SHANDS, H. L., and LEITH, B. D. Vicland oats. Wis. Agr. Exp. Sta. Bul. 462. 1944.
39. STADLER, L. J. Fulghum oats for Missouri. Mo. Agr. Exp. Sta. Bul. 229. 1925.
40. ————, and KIRKPATRICK, R. T. Columbia oats, a new variety for Missouri. Mo. Agr. Exp. Sta. Bul. 296. 1931.
41. STANTON, T. R. Fulghum oats. U. S. D. A. Circ. 193. 1921.
42. ————. Superior germ plasm in oats. U. S. D. A. Yearbook, 1936:347–414. 1936.
43. ————. Registration of varieties and strains of oats, IV, V, VIII, IX, X, XI, XII, and XIII. Jour. Amer. Soc. Agron., 21:1175–1180, 1929; 23:1013–1017, 1931; 30:1030–1036, 1938; 32:76–82, 1940; 33:246–251, 1941; 34:275–279, 1942; 35:242–244, 1943; and 36:445–446. 1944.
44. ————, and COFFMAN, F. A. Spring-sown red oats. U. S. D. A. Farmer's Bul. 1583. 1929.
45. ————, ————. Grow disease-resistant oats. U. S. D. A. Farmer's Bul. 1941. 1943.
46. ————, ————. Disease-resistant and hardy oats for the South. U. S. D. A. Farmer's Bul. 1947. 1943.
47. ————, LOVE, H. H., and DOWN, E. E. Registration of varieties and strains of oats, II. Jour. Amer. Soc. Agron., 19:1031–1037, 1927.
48. ————, and MURPHY, H. C. Oat varieties highly resistant to crown rust and their probable agronomic value. Jour. Amer. Soc. Agron., 25:674–683. 1933.
49. ————, ————. Field studies of smut resistance in oats. Jour. Amer. Soc. Agron., 34:248–258. 1942.

50. ———, ———, COFFMAN, F. A., BURNETT, L. C., and HUMPHREY, H. B. New disease-resistant early oats from a Victoria-Richland cross. Jour. Amer. Soc. Agron., 30:998–1009. 1938.
51. ———, ———, ———, and HUMPHREY, H. B. Development of oats resistant to smuts and rusts. Phytopath., 24:165–167. 1934.
52. TAYLOR, J. W., and COFFMAN, F. A. Effects of vernalization on certain varieties of oats. Jour. Amer. Soc. Agron., 30:1010–1919. 1938.
53. TORRIE, JAMES H. Correlated inheritance in oats of reaction to smuts, crown rust, stem rust, and other characters. Jour. Agr. Res., 59:783–804. 1939.
54. WARBURTON, C. W. Sixty-Day and Kherson oats. U. S. D. A. Farmers' Bul. 395. 1910.
55. ———, and STANTON, T. R. Experiments with Kherson and Sixty-Day oats. U. S. D. A. Bul. 823. 1920.
56. WELSH, J. N. The synthetic production of oat varieties resistant to race 6 and certain other physiologic races of oat stem rust. Can. Jour. Res., 15:58–69. 1937.
57. WIANCKO, A. T., and MULVEY, R. R. Soils and Crops Experiment Farm: Report of progress, 1915–1934. Purdue Univ. Agr. Exp. Sta. 1934.
58. ———, MULVEY, R. R., and MILES, S. R. Soils and Crops Experiment Farm: Report of Progress 1915–1938. Purdue Univ. Agr. Exp. Sta. Circ. 242. 1939.
59. WORZELLA, W. W., HUME, A. N., GRAFIUS, J. E., ERICKSON, E. L., FRANZKE, C. J., and NORGAARD, U. J. South Dakota crop varieties. S. D. Agr. Ext. Ser. Circ. 407. 1944.

STUDIES ON SMUT-RESISTANT OATS FOR KANSAS[1]

E. D. HANSING, E. G. HEYNE, AND L. E. MELCHERS[2]

LOOSE smut, *Ustilago avenae* (Pers.) Rostr., and covered smut, *U. kolleri* Wille (*U. levis* (Kell. and Swing.) Magn.), are major diseases of oats in Kansas. The average annual loss due to these diseases during the last 10 years in Kansas has been estimated at 1,400,000 bushels of grain. Although oat smut may be controlled by treating the seed with New Improved Ceresan or formaldehyde, it can be controlled more economically and satisfactorily by growing resistant varieties.

The development of smut-resistant varieties of oats for Kansas has been a cooperative project between the departments of Botany and Agronomy, Kansas Agricultural Experiment Station, Manhattan, Kans., and the Bureau of Plant Industry, Soils, and Agricultural Engineering, U. S. Dept. of Agriculture. A brief record of the experiments is presented.

EXPERIMENTS ON KANOTA OATS (C.I. 839)[3]

In 1916, the Kansas Agricultural Experiment Station obtained seed stock of a Fulghum type oat from the Robert Nicholson Seed Company, Dallas, Tex. Preliminary tests on disease resistance were made by L. E. Melchers and S. C. Salmon. In 1919, seed of this Fulghum type oat was distributed to farmers in Kansas under the name of Kansas Fulghum but later was named Kanota (6, 7, 9).[4] Superior characteristics claimed for Kanota were high yield, high test weight, earliness, and smut resistance. Kanota was susceptible to crown rust and stem rust.

In 1919, most of the acreage of oats in Kansas was planted to Red Rustproof, Kherson, and Burt type oats (1). Only a very small percentage of the acreage was planted to the Fulghum type oats. By 1939, however, 75% of the oat acreage in Kansas was planted to Kanota.

Kanota was resistant to "Richland"[5] loose smut inoculum, the smut used when the reaction to disease of Kanota was studied prior

[1]Joint contribution from the Departments of Botany and Agronomy, Kansas Agricultural Experiment Station, Manhattan, Kans., and the Division of Cereal Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture. Contribution No. 462, Department of Botany and No. 365, Department of Agronomy. Received for publication February 28, 1945.

[2]Assistant Plant Pathologist, Kansas Agricultural Experiment Station; Associate Agronomist, Division of Cereal Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering; and Plant Pathologist, Kansas Agricultural Experiment Station, respectively. Credit is due to C. O. Johnston, Division of Cereal Crops and Diseases, Manhattan, Kans.; C. H. Ficke, formerly with the Division of Cereal Crops and Diseases, Manhattan, Kans.; C. L. Lefebvre and D. B. Creager, formerly with the Department of Botany; and J. H. Parker, formerly with the Department of Agronomy, Kansas Agricultural Experiment Station, Manhattan, Kans., for aid in phases of this investigation.

[3]C.I. refers to accession number of the Division of Cereal Crops and Diseases.

[4]Reference by number in parenthesis is to "Literature Cited", p. 508.

[5]Physiologic races of smut to which Richland oats are susceptible.

to its distribution. Furthermore, for several years after this variety was distributed in Kansas it continued to be resistant to smut. However, there existed physiologic races of loose smut in the southern oat-growing area of the United States to which most Fulghum type oats were susceptible (3, 4, 5). As Kanota increased in acreage in Kansas "Fulghum"[6] loose smut gradually increased on this variety until it was fairly common. It is believed that this smut spread into Kansas primarily from the southern oat-growing area of the United States since observations indicated that at first smut was more prevalent in fields of this variety in the southeastern part of the state. By 1928 Kanota no longer could be classified as a resistant variety in Kansas. In fact, it was so susceptible to the Fulghum smut that it was used later as a susceptible check variety in the oat smut breeding investigations.

In 1927, five collections of loose smut were made in fields of Kanota in Kansas, Oklahoma, and Texas and in 1928 were used to test the reaction of seven varieties of oats. Additional varieties were included in 1929 and 1930. The smut from the nursery at Manhattan was also used as inoculum. The data indicated that there were two definite groups of loose smut (Table 1). Markton was highly resistant, while Red Texas, Red Rustproof, and Burt were moderately resistant to both groups of smut. Fulghum and Kanota were resistant to the Richland smut but susceptible to the Fulghum smut. Fowld's Hulless was susceptible to both groups of smut.

In another experiment in 1928, Fulghum, Kanota, and 34 selections of Fulghum were inoculated with the Fulghum smut and planted in the field. In this experiment Fulghum and Kanota had 45 and 59% smut, resepctively. The 34 Fulghum selections were all susceptible with from 27 to 76% infection.

In 1929 and 1930, four collections of Richland smut and three collections of Fulghum smut were used to test the reaction of some of the same and additional varieties to the groups of smut. Navarro and Nortex were highly resistant, not showing any infection for either group of smut (Table 1). Richland was susceptible to the Richland smut but resistant to the Fulghum smut. Frazier, a Fulghum type selection from Red Rustproof, was resistant to the Richland smut but susceptible to the Fulghum smut. None of these varieties was well adapted to Kansas conditions.

Since the isolation of this loose smut to which Fulghum is susceptible, Reed (4) has reported six races of loose smut and three races of covered smut to which Fulghum is susceptible. Several races of Fulghum loose and covered smut have been collected in Kansas.

EXPERIMENTS ON FULTON OATS (C.I. 3327)

Fulton originated from the cross Fulghum × Markton oats made in 1926 by G. A. Wiebe at the Aberdeen Substation, Aberdeen, Idaho. The purpose of the cross was to introduce the smut resistance of Markton into the Fulghum type oats (8). From 1928 to 1930 the

[6]Physiologic races of smut to which Fulghum oats are susceptible.

TABLE 1.—*Reaction of 11 varieties of oats to nine collections of smut, Manhattan, Kans., 1928 to 1930.**

Source of smut		Percentage smut											
Location	Variety	Markton C. I. 2053	Navarro C. I. 966	Nortex C. I. 2382	Red Texas Tex. 768	Red Rustproof C. I. 1355	Burt C. I. 1861	Richland C. I. 787	Frazier C. I. 2381	Fulghum C.I. 708	Kanota C. I. 839	Fowld's Hulless C. I. 1996	Mean
"Richland" Smut Group													
Belleville, Kans....		T†	0	0	0	3	13	31	2	6	4	—	6
Blue Rapids, Kans.		0	0	0	0	4	13	64	2	8	4	—	10
Columbus, Kans....	White oats	0	0	0	0	4	13	56	1	2	2	—	8
Manhattan, Kans..	Albion	T	0	0	0	4	7	26	2	2	2	54	9
Mean..........		T	0	0	0	4	11	44	2	4	3	54	11
"Fulghum" Smut Group													
Columbus, Kans....	Kanota	0	—	—	3	6	7	—	—	70	77	50	30
Anthony, Kans....	Kanota	0	—	—	3	12	3	—	—	64	75	43	29
Stillwater, Okla....	Kanota	0	0	0	1	10	4	2	53	50	66	40	21
Roosevelt, Okla....	Kanota	0	0	0	4	6	2	1	38	38	61	36	17
Denton, Texas.....	Kanota	T	0	0	1	8	5	2	36	51	54	47	19
Mean..........		T	0	0	2	8	4	2	42	55	67	43	20

*The variety Fowld's Hulless was used only in 1928, while the varieties Navarro, Nortex, Richland, and Frazier were used only in 1929 and 1930. The smut collections on Kanota from Columbus and Anthony, Kans., were used only in 1928, while the smut collections from Belleville, Blue Rapids, and on common white oats from Columbus, Kans., were used only in 1929 and 1930.

†T = 0.1 to 0.5% infection.

F_3 to F_5 generations of these crosses were inoculated with a composite of chlamydospores made up of 15 collections of loose and covered smuts from Kansas. Fulton was selected as a promising smut-resistant selection in 1930. From 1931 to 1938, an average of 0.5 and 25% of the panicles in Fulton and Kanota, respectively, were infected when the seed was dusted with a composite of the Kansas collections of loose and covered smuts. Fulton was distributed to Kansas farmers in 1939 because of its smut resistance and desirable agronomic qualities.

In 1934, several of the Fulghum × Markton selections in the oat smut breeding nursery had a few smutted panicles. These panicles were collected, and the smut was purified and increased and is hereafter designated the "Fulton" race of loose smut.[7] In 1935, the Fulton smut collected in 1934 was used to inoculate seed with hulls on and hulls off of Fulton and five other selections from the Fulghum × Markton crosses. Fulton, C. I. 3220, and Kans. Sel. 303633 were found to be susceptible, while Kans. 6137, C. I. 3332, and C. I. 3333 appeared resistant (Table 2). The susceptible selections averaged 16% infected panicles, as compared with only 2% in the resistant selections. Approximately three times as much smut was obtained when the seed was inoculated with hulls off as compared with hulls on. This marked difference in reaction to smut when seed is inoculated with hulls off as compared with hulls on was first demonstrated by Johnston (2).

In 1936, Fulghum, Markton, and the Fulghum × Markton selections used in the 1935 experiment were inoculated with the Fulton smut and with the composite of 40 collections of smut from Kansas (Table 3). In one set the hulls were left on, while in the other set the hulls were removed before the seed was inoculated.

TABLE 2.—*Reaction of Fulghum×Markton selections to Fulton smut, Manhattan, Kans., 1935.**

Variety or selection	Accession No.	Percentage smut†	
		Hulls on	Hulls off
Fulton	C.I. 3327	6	28
Fulghum×Markton	C.I. 3220	7	8
Fulghum×Markton	Ks. Sel. 303633	10	32
Mean of susceptible selections		8	23
Fulghum×Markton	Ks. 6137	T‡	5
Fulghum×Markton	C.I. 3332	0	2
Fulghum×Markton	C.I. 3333	0	1
Mean of resistant selections		T	3

*Smut collected in 1934 from resistant Fulghum × Markton selections in the oat smut breeding nursery.
†Based on single 8-foot rows.
‡T = 0.1 to 0.5% infection.

[7]Physiologic race of smut to which Fulton oats are intermediate in susceptibility.

Fulghum was susceptible to the Fulton smut and to the composite smut, while Markton was highly resistant to both smuts. When seed with hulls on as compared with hulls off was inoculated with the Fulton smut, the susceptible selections averaged 13 and 72%, respectively, while the resistant selections averaged 2 and 10%, respectively. Similarly, when the seed was inoculated with the composite smut, the susceptible selections averaged 2 and 6%, respectively, while the resistant selections averaged a trace and 1%, respectively.

TABLE 3.—*Reaction of Fulghum×Markton selections and parents to smut, at Manhattan Kans., 1936.*

Variety or selection	Accession No.	Percentage smut*			
		Fulton smut		Composite smut†	
		Hulls on	Hulls off	Hulls on	Hulls off
Fulghum	C.I. 708	56	76	45	86
Markton	C.I. 2053	0	0	0	0
Fulton	C.I. 3327	17	85	2	6
Fulghum×Markton	C.I. 3220	10	66	2	6
Fulghum×Markton	Ks. Sel. 303633	12	64	2	6
Mean of susceptible selections		13	72	2	6
Fulghum×Markton	Ks. 6137	4	17	1	2
Fulghum×Markton	C.I. 3332	1	5	T‡	1
Fulghum×Markton	C.I. 3333	1	7	T	1
Mean of resistant selections		2	10	T	1

*Average of five replications.
†Composite of 40 Kansas collections of loose and covered smut. A few of the collections included a small percentage of the Fulton smut.
‡T = 0.1 to 0.5% infection.

The experimental results of 1935 and 1936 indicated that Fulton was susceptible to a new race of loose smut; however, when the hulls were left on when inoculating the seed, Fulton exhibited only an intermediate type of susceptibility as compared with Fulghum.

Although Fulton was intermediate in susceptibility to the Fulton smut while several closely related lines were resistant, it was approved for distribution by the Kansas Agricultural Experiment Station partly because of its superior agronomic characteristics. Furthermore, the available data indicated a rather limited distribution of this physiologic race of Fulton smut in Kansas. In 1939, this hypothesis was verified by inoculating Fulton seed by the partial evacuation method with all of the Kansas collections. Fulton gave only a zero or trace infection for most of the races of smut with a maximum of 5% infection for a few of the collections. When inoculated with Fulton smut, it had 43% infection. Since Fulton was distributed

in 1939, most of the fields of this variety in Kansas have shown none or only a trace of smut. As high as 10% smut has been recorded in a few fields, but there has been no annual increase in smut in Fulton such as was encountered in the case of the Fulghum smut in Kanota.

Since some of the closely related lines of Fulton were resistant to the Fulton smut, an attempt was made to reselect in Fulton to get a resistant strain of this variety. In 1939, 56 Fulton selections were inoculated with equal portions of the Fulton smut and a composite of all Kansas smut collections. Based on single 8-foot rows the percentage of smut in the selections ranged from 4 to 21%, with an average of 11%. The four Fulton checks averaged 14% and the four Kanota checks 36%. Thirty of the selections with low smut infection were bulked and assigned Kans. 5414. These 30 selections averaged 9% smutted panicles.

In 1940, Fulghum, Markton, Fulton, Kans. 5414, and five other Fulton selections were inoculated by partial evacuation with Fulton smut and with the Kansas composite smut of 100 county collections and planted in triplicated 8-foot rows. All of the selections had about the same reaction as Fulton to the Fulton smut (Table 4). It was concluded then that further reselection work in Fulton would probably be of no value in isolating a strain of oats resistant to the Fulton smut.

Although Fulton has shown some susceptibility to one race of loose smut in Kansas it is apparently well liked by farmers in the state. In 1944 it was estimated that 40% of the acreage of oats in Kansas was planted to Fulton, 45% to Kanota, and 15% to other varieties.

TABLE 4.—*Reaction of Fulton selections and parents to smut, at Manhattan, Kans., 1940.**

Variety or selection	Accession No.	Percentage smut†	
		Fulton smut	Composite smut‡
Fulghum	C.I. 708	87	62
Markton	C.I. 2053	0	0
Fulton	C.I. 3327	60	5
Fulton reselection	Ks. 5414§	39	6
Fulton reselection	Ks. 392	50	2
Fulton reselection	Ks. 395	48	0
Fulton reselection	Ks. 3914	62	1
Fulton reselection	Ks. 3933	45	6
Fulton reselection	Ks. 3939	42	3
Mean Fulton and Fultion reselections		49	3

*Seed inoculated by partial evacuation.
†Average of three replications.
‡Composite of 100 Kansas collections of loose and covered smut. A few of the collections included a small percentage of the Fulton smut.
§Bulk of 30 reselections out of Fulton other than those reported in this table.

EXPERIMENTS ON OSAGE (C.I. 3991), NEOSHO (C.I. 4141), AND OTHER NEW OAT STRAINS

A severe crown rust epidemic in 1935 emphasized the need for adapted varieties with resistance to the rusts as well as the smuts. As a consequence, crosses were made between a number of Fulghum × Markton strains, including Fulton and segregates of the Victoria × Richland crosses at Aberdeen, Idaho (1).

In 1938 and following years a large number of selections were studied in the Manhattan oat rust and smut breeding nurseries. The seed was inoculated with the Kansas composite oat smut, including physiologic races of both loose and covered smuts. During 1938, 1939, 1940, and 1941, 800 selections of Fulton × (Victoria × Richland) were grown in the nursery. Twenty-eight per cent of the selections had one or more heads of smut per head row and were discarded. During the same period, 1,800 selections of (Fulghum × Markton) × (Victoria × Richland) were grown. Twelve per cent of these selections showed one or more smutted panicles per head row and were discarded.

The difference in the percentage of selections eliminated is explained on the basis that some of the Fulghum × Markton selections used as parents in these crosses were not so susceptible to the Fulton smut as was Fulton. In 1940, 40% of the Fulton × (Victoria × Richland) selections were infected with smut as compared with 29, 22, 15, 9, 8, and 0% of the selections from the other six (Fulghum × Markton) × (Victoria × Richland) crosses. In one of these crosses the Fulghum × Markton Fulton smut resistant selection C.I. 3333 (Tables 2, 3) was used as one parent and none of the 102 selections of this cross was smutted.

Selections which did not show any smut, were resistant to rust, and appeared good agronomically were included in the advanced oat yield and oat smut nurseries. For the smut nursery the seed of each variety or strain was divided into three lots; one was inoculated with Fulton smut, another with a composite of Kansas Fulghum smut, and a third with a composite of Kansas Richland smut. Inoculations were made by the partial evacuation method with a suspension of chlamydospores.

In 1941 and 1942 environmental conditions were very favorable for smut infection, while in 1943 they were only fair for smut infection. In 1944 the soil was very cold and wet between planting and emergence of the inoculated seed and very low infection was obtained, especially on oat strains which had previously shown an intermediate type of susceptibility.

The data for these tests, given in Table 5, show that Fulton was intermediate in susceptibility to the Fulton smut but highly resistant to the Fulghum smut and the Richland smut. Kanota was very susceptible to the Fulton and Fulghum smuts but resistant to the Richland smut. Richland was resistant to the Fulton and Fulghum smuts but susceptible to the Richland smut.

Markton, Trojan, Brunker, Otoe, New Nortex, Tama, Boone, and Fultex were highly resistant to all groups of smut (Table 5).

TABLE 5.—*Reaction of oat varieties and selections to smut at Manhattan, Kans.*

Variety or selection	C. I. No.	Percentage infection by smuts*															
		Fulton smut					Fulghum smut					Richland smut					All tests
		1941	1942	1943	1944	Mean	1941	1942	1943	1944	Mean	1941	1942	1943	1944	Mean	
Smut tester varieties:																	
Fulton	3327	34	20	7	1	16	1	T†	T	0	T	T	1	T	0	T	5
Kanota	839	77	68	55	16	54	63	93	68	19	61	8	3	T	1	3	39
Richland	787	2	1	0	T	1	3	1	0	T	1	39	47	21	9	29	10
Other varieties:																	
Markton	2053	0	T	0	0	T	0	0	0	0	0	0	T	0	0	T	T
Trojan	2491	1	0	T	0	T	0	0	0	0	0	4	T	0	0	1	T
Brunker	2054	3	0	T	0	1	T	0	0	0	T	0	0	0	0	0	T
Otoe	2886	—	0	0	0	0	—	0	0	0	0	—	0	0	0	0	0
New Nortex	3422	—	0	0	0	0	—	3	0	0	1	—	0	0	0	0	0
Columbia	2820	12	10	10	1	8	0	1	0	T	T	5	2	1	0	2	4
Marion	3247	11	2	1	T	4	0	0	0	0	0	1	0	0	0	T	1
Tama	3502	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Boone	3305	—	0	0	0	0	—	0	0	0	0	—	0	0	0	0	0
Fultex	3531	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fulton × (Victoria × Richland):																	
Osage	3991	—	18	4	1	8	—	0	0	0	0	—	1	0	0	T	3
Ventura	3989	—	34	6	T	13	—	0	0	0	0	—	0	0	0	0	4
Unnamed sel. Ks. 384948		—	0	0	—	0	—	2	0	—	1	—	0	0	—	0	T
Unnamed sel. Ks. 41369		—	—	0	0	0	—	—	0	0	0	—	—	0	0	0	0
(Fulghum × Markton) × (Victoria × Richland):																	
Neosho	4141	—	0	0	0	0	—	0	0	0	0	—	0	0	0	0	0
Unnamed selection	4140	—	0	0	0	0	—	0	0	0	0	—	0	0	0	0	0
Mean		14	8	4	1	6	7	6	4	1	3	6	3	1	1	2	4

*Fulton smut = Kansas collection of *Ustilago avenae*; Fulghum smut = Kansas collections of *U. avenae* and *U. kolleri*, except Fulton smut; Richland smut = Kansas collections of *U. avenae* and *U. kolleri*.

†T = 0.1 to 0.5% infection.

Although the Victoria oat C.I. 2401 was not included in these experiments, it has been highly resistant in other experiments at Manhattan, even when seed with hulls off was inoculated with composite smut inoculum containing one-third Fulton smut.

Columbia, a Fulghum selection, and Marion, a selection from Markton × Rainbow, had an intermediate reaction to the Fulton smut; however, they were not so heavily infected as Fulton (Table 5). Columbia and Marion were resistant to the Fulghum and Richland smuts.

Twenty-two selections of the cross Fulton × (Victoria × Richland) were tested from 1941 to 1943. Of these, 17 were similar to Fulton in susceptibility, while four were highly resistant. All of these selections were highly resistant to the Fulghum and Richland smuts. Many of these selections in the oat breeding nursery and in the oat smut nursery have been intermediate in susceptibility to the Fulton smut; therefore, it has been difficult to select a resistant strain that also has good yield and quality. Osage and Ventura, two good selections from this cross, are intermediate in susceptibility to the Fulton smut. Other selections from the same cross, notably Kansas selections 384948, 394894, 394962, 41369, and 41397, have been highly resistant to the Fulton smut but are not so promising agronomically as Osage and Ventura.

In the oat smut nursery most of the selections derived from the (Fulghum × Markton) × (Victoria × Richland) crosses were resistant to the Fulton smut. In 1941, 1942, and 1943, 1, 2, and 2 selections, respectively, were intermediate in susceptibility to the Fulton smut, while 19, 46, and 47 selections were highly resistant. All of these selections were highly resistant to the Fulghum and Richland smuts. Neosho and C.I. 4140 are among the most promising selections from these crosses (1).

Osage and Neosho are resistant to the common races of crown and stem rusts and have good agronomic qualities. These two varieties have been approved for distribution in Kansas in the spring of 1945 (1).

SUMMARY

Kanota, C.I. 839, a strain of Fulghum, was distributed in 1919 as a smut-resistant variety by the Kansas Agricultural Experiment Station. However, smut existed in the southern oat-growing area of the United States to which most Fulghum type oats were susceptible. As Kanota increased in acreage, this Fulghum smut gradually increased until it was fairly common and Kanota could no longer be classified as a resistant variety in Kansas.

Fulton, C.I. 3327, a selection from a cross Fulghum × Markton, made in 1926, was developed to obtain a smut-resistant red oat. It was distributed by the Kansas Agricultural Experiment Station in 1939.

In 1935 and 1936 it was proved that Fulton was intermediate in susceptibility to a new physiologic race of loose smut. This race existed as a slight mixture in a few of the Kansas collections of oat smut and was purified by increasing it on Fulton.

Kanota and Fulghum were susceptible, while Columbia and Marion were intermediate in susceptibility to the Fulton smut. Richland, Markton, Trojan, Brunker, Otoe, New Nortex, Tama, Boone, Fultex, and Victoria were highly resistant to this race of smut.

In 1935, two crosses were made between Fulton and Victoria × Richland and several additional crosses between Fulghum × Markton selections and Victoria × Richland selections. Most of the Fulton × (Victoria × Richland) selections, including the promising varieties Osage and Ventura, eventually proved intermediate in susceptibility to the Fulton smut.

Most of the (Fulghum × Markton) × (Victoria × Richland) selections, including the variety Neosho and the promising selection C.I. 4140, were highly resistant to the Fulton smut.

All of the varieties and hybrid selections included in these experiments were resistant to the Fulghum smut, except Fulghum, Kanota, Frazier, and Fowld's Hulless. Burt and Red Rustproof had a low percentage of infection with Fulghum smut but are classed as resistant varieties.

All strains were considered resistant to the Richland smut, except Richland and Fowld's Hulless, although Red Rustproof and Burt had 4 and 11% infection, respectively.

Osage and Neosho have been distributed to Kansas farmers for increase in 1945.

LITERATURE CITED

1. Coffman, F. A., Heyne, E. G., Johnston, C. O., Stevens, Harland, and Murphy, H. C. Improvement and distribution of spring-sown red oats. Jour. Amer. Soc. Agron., 37:479–498. 1945.
2. Johnston, C. O. Effects of soil moisture and temperature and of dehulling on the infection of oats by loose and covered smuts. Phytopath., 27:31–36. 1927.
3. Reed, G. M. Further evidence of physiologic races of oat smuts. Mycologia, 19:21–28. 1927.
4. ———. Physiologic races of oat smuts. Amer. Jour. Bot., 27:135–143. 1940.
5. ———, and Stanton, T. R. Reaction of oat varieties to physiologic races of loose and covered smuts of red oats. Jour. Agr. Res., 52:1–15. 1936.
6. Salmon, S. C., and Parker, John H. Kanota: An early oat for Kansas. Kans. Agr. Exp. Sta. Circ. 91. 1921.
7. Stanton, T. R. Fulghum oats. U. S. D. A. Circ. 193. 1921.
8. ———. Registration of varieties and strains of oats. VIII. Jour. Amer. Soc. Agron., 30:1030–1036. 1938.
9. ———, Love, H. H., and Down, E. E. Registration of varieties and strains of oats. II. Jour. Amer. Soc. Agron., 19:1031–1037. 1927.

JOURNAL

OF THE

American Society of Agronomy

VOL. 37 | JULY, 1945 | NO. 7

SOIL REACTION AS AFFECTED BY PLOWING UNDER HAIRY VETCH[1]

E. B. REYNOLDS, W. R. COWLEY, AND J. C. SMITH[2]

THE effect of plowing under green-manure crops on soil reaction has been studied by several workers. Pieters (10)[3] in his comprehensive treatise on all phases of green manuring has pointed out that workers have obtained widely different results from similar investigations. Since soil reaction has a profound influence on the physical, chemical, and biological properties of soil, these conflicting results indicate the need of additional work to determine definitely the effect of plowing under green manures on the soil reaction. This is especially true in the southern states where the soils are chiefly noncalcareous and have small buffer capacity.

During the last several years the Texas Agricultural Experiment Station has been conducting experiments on the broad aspects of green manuring. These experiments have provided an opportunity to study the effect of plowing under green manure on soil reaction. The purpose of this paper is to report the results of studies on soil reaction in green manure experiments with hairy vetch on Lufkin fine sandy loam at College Station, Tex., which have been conducted since 1937. These studies on soil reaction, however, were made only in 1940, 1941, and 1942.

REVIEW OF LITERATURE

The effect of green manures on soil reaction has been studied in field and laboratory experiments. Pieters (10) in his review stated that the results reported from field trials did not show that green manures, in general, had increased acidity, although some workers have reported distinct increases in soil acidity in pot experiments.

Howard (6) found no evidence that any acidity resulted from the use of rye as a cover crop for a quarter of a century. Ames and Schollenberger (1) in reporting the results of field experiments in Ohio over a period of 23 years state that, "Field observations and tests made do not indicate that organic matter furnished by green crops causes acidity in soil". Miller (9) in Missouri concluded from his work that, "Ordinary green manures turned under either dry or fresh do not increase soil acidity, although a crop containing much sugar, as in the case of sorghum, does apparently increase soil acidity for a few weeks. This acidity later decreases." In greenhouse studies on Leonardtown clay loam, Smith and Humfeld (13) reported that, "Green manuring produced no definite change in the hydrogen-ion concentration of the soil". Thom and Smith (14) stated that, "Green

[1]Contribution from the Division of Agronomy, Texas Agricultural Experiment Station, College Station, Tex. Received for publication February 26, 1945.

[2]Chief, Division of Agronomy, Instructor, Department of Agronomy, A. & M. College of Texas, and Agronomist, Division of Agronomy, Texas Agricultural Experiment Station, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 513.

manures plowed into soils in good tillable condition are broken down principally by bacterial activity without affecting or being affected by the acidity of the surrounding soil".

In studies on southeastern Coastal Plain soils, Lewis and Hunter (8) reported that, "The pH is generally lowered by the use of green manures on all the soils".

Other workers have studied the effect of turning under green manures on soil reaction. Pieters (10) in his review of the literature pointed out that the results obtained were somewhat conflicting but tended to show that green manures do not increase soil acidity.

PLAN OF THE EXPERIMENT

Five treatments were included in the field work connected with these studies, *viz.*, (a) vetch alone, (b) vetch and 0–8–4 fertilizer, (c) vetch and 4–8–4 fertilizer, (d) 4–8–4 fertilizer, and (e) omission of both vetch and fertilizer. The treatments were replicated six times in randomized blocks. The plots were 125 feet long and 18 feet wide. The fertilizer was applied at the rate of 500 pounds per acre, 300 pounds to the vetch in the fall and 200 pounds per acre to cotton in the spring. All of the nitrogen, however, was applied to the cotton. Hairy vetch was planted in the fall on a well-prepared seedbed and plowed under in the spring, usually about March 15. Cotton was planted on this land 3 or 4 weeks later.

An area 34.25 feet long and 18 feet wide at one end of each plot was not planted to cotton but was left fallow after plowing under of the vetch. This fallowed portion was kept free of weeds by cultivation in the same manner as the portion planted to cotton. This made it possible to observe the effect of the green manure on the reaction of the soil under fallow and under growing cotton.

Representative samples of soil from the A horizon only were used in making the pH determinations. These samples were obtained by taking random samples at eight different locations to a depth of 8 inches on the cotton and fallowed portions of the plot and mixing them thoroughly to form a composite sample for each land use treatment (cotton and fallow). Samples were taken May 27, July 7, and September 9, 1940; June 26 and July 28, 1941; and June 8 and July 3, 1942. The samples were taken to the laboratory, air-dried, and placed in Mason jars. The pH was determined with the glass electrode (2, 4). The values reported as average pH were calculated in terms of hydrogen-ion concentration and then converted into equivalent pH.

EXPERIMENTAL RESULTS

Although this paper is concerned chiefly with soil reaction, it is pertinent to give here the yield of vetch because the amount of green material plowed into the soil is correlated with soil reaction, as will be shown later. The yield of vetch in 1941 and the average yield for the 5 years 1937–42 are given in Table 1. It will be observed that the soil which received phosphorus produced considerably more vetch than the soil which did not receive phosphorus. On the fallowed areas phosphorus more than doubled the yield of vetch in 1941. Although vetch samples were taken separately only in 1941 from the cropped and fallowed plots, the greater growth of vetch on the fallowed portion was evident in 1940, 1941, and 1942.

The pH values found in the course of these studies are given in Table 2. Statistical analysis of the data show that there was a highly

TABLE 1.—*Average yield in tons of air-dry vetch per acre.*

Treatment	Average yield of vetch, 1937–42	Yield of vetch in 1941 on: Plots planted to cotton	Yield of vetch in 1941 on: Fallowed plots
Vetch plus 4–8–4	1.37	1.85	2.45
Vetch plus 0–8–4	1.31	1.60	2.08
Vetch	0.91	0.94	1.06

TABLE 2.—*Average pH for the different land use treatments, 1940–42.*

Treatment	Average pH															
	1940						1941				1942				Average	
	May 27		July 22		Sept. 9		June 26		July 28		June 8		July 3			
	Cot-ton	Fal-low	Cot-ton	Fal-low	Cot-ton	Fal-low	Cot-ton	Fal-low	Cot-ton	Fal-low	Cot-ton	Fal-low	Cot-ton	Fal-low	Cot-ton	Fal-low
Vetch plus 4–8–4	4.46	4.36	4.90	4.79	4.43	4.48	4.55	4.40	4.75	4.22	4.55	4.49	4.69	4.58	4.60	4.42
Vetch plus 0–8–4	4.36	4.25	4.77	4.69	4.35	4.34	4.66	4.12	4.85	4.24	4.58	4.46	4.74	4.71	4.60	4.35
Vetch..........	4.49	4.41	4.81	4.69	4.40	4.36	4.70	4.51	4.84	4.18	4.66	4.46	4.68	4.61	4.65	4.43
Untreated......	4.83	4.72	5.14	4.96	4.53	4.54	5.37	5.15	5.25	4.54	5.20	5.23	5.21	5.06	5.02	4.83
4–8–4..........	4.79	4.69	5.18	5.04	4.69	4.62	5.41	4.94	5.37	4.82	5.34	5.24	5.40	5.26	5.12	4.91

significant difference between the mean pH of the soil on all of the plots receiving different treatments. A mean difference in hydrogen-ion concentration of $.101 \times 10^{-5}$ and $.134 \times 10^{-5}$ is required for significance between treatments mean on the .01 and .05 level, respectively. The average pH of the soil on all plots on which vetch had been turned under was significantly lower than that of the soil on the untreated plots at all sampling dates, indicating the vetch material had a decided effect upon the reaction of the soil. Although the increase in hydrogen-ion concentration evidently resulted from the decomposition of the green manure, an explanation of the exact processes involved in the change is not attempted here. Smith (11) in working on another phase of these studies on green manure found that a much higher nitrate level was maintained on the plots receiving vetch. This indicated that the increased rate of nitrification and the accumulation of nitrates was to some extent responsible for the increased acidity (12). The solubility of the bases and the loss of bases by leaching probably were accelerated by the decomposition of the vetch (7). The average pH of the plots receiving only 4–8–4 fertilizer, which was generally higher than that of the untreated plots, evidently was influenced by the basic residual effect of the fertilizer.

The average pH of the soil on the fallowed plots was significantly lower than that of the soil on plots planted to cotton. The factors which evidently are responsible for the greater hydrogen-ion concentration of the soil in the fallowed plots receiving green manure are the larger amounts of green material turned under, the greater accumulation of nitrates in the soil, and probably more leaching due to the absence of crop cover in the summer. The slightly lower mean pH of the fallowed portion of the plots which received no green manure may be attributed to leaching in the absence of crop cover and to seasonal fluctuations of the normal nitrate level. The differential response of treatments to land use (cropped and fallowed) probably was due to the difference in the amounts of vetch plowed under and to the residual effect of the fertilizer.

Highly significant differences in pH values were found at the different sampling dates in 1940 and 1942. Preliminary work on these plots (11) showed that the nitrates in the soil reached two peaks during the months considered in this test, the highest levels being attained in the latter part of May or the first of June, and in the first part of September, with a definite decline in July. The pH values follow the nitrate curve rather closely. Assuming that the fluctuation of the nitrate level was responsible for the change in pH, the inconsistency of results secured in 1941 can be attributed to the fact that both sampling dates were between the June and September peaks of the nitrate curve when the amounts of nitrates were relatively the same. The data in 1940 and 1942 evidently were secured near enough to the June peak of the nitrate curve to reveal a marked decline in nitrates between the sampling dates. If the data for the one year in which samples were taken in September can be considered significant, the lower values at this date eliminate any explanation of the change in pH on the basis of a fluctuation in the carbon dioxide pressure of the soil.

Since these data were obtained only during the growing season of the cotton, it is impossible to state definitely that the increase in hydrogen-ion concentration of the green-manure plots persists throughout the year. However, since the decomposition of organic matter increases the solubility of the bases and their susceptibility to leaching, it seems that the acidity might be permanently increased because of the textural difference occurring between horizons of the soil profile. Any bases leached into the heavy clay subsoil should be returned very slowly, if at all, to the sandy loam topsoil by ionic migration. Following this line of reasoning, it might be stated that the ultimate effect of green manures on soil reaction could vary with both soil and rainfall characteristics.

SUMMARY

The Texas Agricultural Experiment Station for several years has conducted experiments on the broad aspects of green manuring. In 1940, 1941, and 1942 studies were made to determine the effect of plowing under hairy vetch in these experiments on the reaction of Lufkin fine sandy loam at College Station, Texas. It was found that plowing under hairy vetch produced a significant increase in the acidity of the soil, at least during the growing season of cotton which followed the vetch. The increase in acidity was more pronounced on the fallowed portion of the plots than on the plots planted to cotton. There were some differences in the pH values of soil samples taken at different dates, but the highest pH values were obtained from the samples taken in July.

LITERATURE CITED

1. AMES, J. W., and SCHOLLENBERGER, C. J. Liming and lime requirement of soil. Ohio Agr. Exp. Sta. Bul. 306. 1916.
2. ASSOCIATION OF OFFICIAL AGRICULTURAL CHEMISTS. Official and Tentative Methods. Washington, D. C. Ed. 5. 1940.
3. BAVER, L. D. Soil Physics. New York: John Wiley & Sons, Inc. 1940.
4. CLARK, W. M. The Determination of Hydrogen Ions. Baltimore: The Williams and Wilkins Co. 1928.
5. HILL, H. H. A comparison of methods for determining soil acidity and a study of the effects of green manures on soil acidity. Va. Agr. Exp. Sta. Tech. Bul. 19. 1919.
6. HOWARD, L. P. The reaction of the soil as influenced by the decomposition of green manures. Soil Sci., 9:27–39. 1920.
7. JENSEN, C. A. Effect of decomposing organic matter on the solubility of certain inorganic constituents of the soil. Jour. Agr. Res., 9:253–268. 1917.
8. LEWIS, R. D., and HUNTER, J. H. The nitrogen, organic carbon, and pH of some Southeastern Coastal Plains soils as influenced by green-manure crops. Jour. Amer. Soc. Agron., 32:586–601. 1940.
9. MILLER, M. F. Effect of the addition of organic matter to the soil upon the development of soil acidity. Mo. Agr. Exp. Sta. Bul. 147. 1917.
10. PIETERS, A. J. Green Manuring. New York: John Wiley and Sons, Inc. 1927.
11. SMITH, J. C. The effects of hairy vetch used as a green-manure crop on Lufkin fine sandy loam. Thesis, Agron. Dept., A. & M. College of Texas. 1943.
12. SMITH, N. R., and HUMFELD, H. Effect of rye and vetch green manures on the microflora, nitrates, and hydrogen-ion concentration of two acid and neutralized soils. Jour. Agr. Res., 41:97–123. 1930.
13. ———, ———. The decomposition of green manures grown on a soil and turned under compared to the decomposition of green manures added to a fallow soil. Jour. Agr. Res., 43:715–731. 1931.
14. THOM, C., and SMITH, N. R. The relation of soil acidity to the decomposition of organic residues. Jour. Amer. Soc. Agron., 25:392–396. 1933.

BUNT REACTION OF HARD RED WINTER WHEATS IN 1938-42[1]

K. S. QUISENBERRY, H. A. RODENHISER, AND C. O. JOHNSTON[2]

SINCE the fall of 1930 a coordinated cooperative improvement program for hard red winter wheat has been in operation in the principal winter wheat-growing states of the Great Plains. As a part of this program there has been carried, on a rather extensive scale, a study of the reaction of wheats to bunt. Data obtained during the years 1932 to 1937, inclusive, have been published.[3] Since the general plan of the nursery was changed with the crop of 1943, it seems desirable to present the information available up to that time.

MATERIALS AND METHODS

The general plan as outlined previously was followed in the work reported here. Fifty varieties and strains of wheat were planted in duplicate 6- or 8-foot rows each year. These included (1) new hybrid strains found to be bunt resistant at some stations, (2) varieties from agronomic tests on which more information was desired, and (3) a few wheats primarily adapted for growing in the western wheat region. Two susceptible checks, Kharkof (C. I. 1442)[4] and Cheyenne (C. I. 8885), were included, as well as a few varieties that would give some indication of the physiologic races of the organisms present in the composite mixtures of the inoculum. Except for this group, strains were discontinued when found to be highly susceptible, when it appeared that a satisfactory determination of their bunt reaction had been obtained, or when they proved to be undesirable agronomically.

Seed for the tests was obtained from sources apparently free from bunt and no special treatment was applied. The inoculum for each nursery was a composite of chlamydospores obtained from the previous test at the same station. From time to time collections of inoculum obtained from commercial wheat fields in the area represented by the individual nursery were added to the composite of bunt spores. In these preliminary tests only approximate determinations were made as to the proportions of *Tilletia foetida* (Wallr.) Liro and *T. caries* (D. C.) Tul. that occurred in the mixtures. The inoculum for the Manhattan, Kans., and Denton, Tex., nurseries was pure for *T. foetida*; for the Bozeman and Moccasin, Mont., nurseries there was approximately 30% *T. caries* in the mixture, and only small percentages of this species in the inoculum for the other stations.

In some or all of the 5 years reported, nurseries were grown at Denton and Amarillo, Tex.; Stillwater and Woodward, Okla.; Manhattan, Kans.; Akron and Fort Collins, Colo.; Lincoln and North Platte, Nebr.; St. Paul, Minn.; Moccasin and Bozeman, Mont.; Kearneysville, W. Va.; and Beltsville, Md. At Logan, Utah, clean seed was put into soil that was presumed to be contaminated with the dwarf bunt fungus.

In each row the percentage of bunt was determined by estimating the total number of heads and then counting those bunted. Actual counts of the total number of heads were made on several rows in each nursery to check the accuracy of these estimates.

---

[1]Cooperative investigations of the Division of Cereal Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture, and the agricultural experiment stations of Texas, Oklahoma, Kansas, Colorado, Nebraska, Minnesota, Montana, Utah, and West Virginia. Received for publication March 8, 1945.

[2]Senior Agronomist, Senior Pathologist, and Pathologist, respectively, Division of Cereal Crops and Diseases. The writers express their appreciation to cooperators at the various experiment stations for their kindness in growing the nurseries and furnishing data.

[3]RODENHISER, H. A., and QUISENBERRY, K. S. Bunt reaction of some varieties of hard red winter wheat. Jour. Amer. Soc. Agron., 30:484-492. 1938.

[4]C. I. refers to accession number of the Division of Cereal Crops and Diseases.

DATA OBTAINED

A summary of the data obtained at the different stations is presented in Table 1, Data were not recorded from all stations every year because of unfavorable environmental conditions for bunt infection or for plant growth. Data were obtained from 10 stations in 1938–41 and from 11 stations in 1942. Since all varieties were not grown for all of the years, the average percentage of infection is shown in terms of percentages of Kharkof (C.I. 1442) grown in comparable experiments. In this way varieties may be compared directly. The varieties are listed in Table 1 in order of resistance as expressed in terms of Kharkof check.

A total of 123 varieties and strains were tested for 1 to 5 years during the period 1938 to 1942. No variety was entirely free from bunt in all tests, but three averaged less than 1% and are recorded in the table as trace. Six varieties had averages of 1%. Some of the named varieties showing the most resistance were Hohenheimer, Relief, Hussar, Albit, Nebred, Ridit, Yogo, Minturki, Comanche, and Oro. The average infection for Oro was 10% for the period 1938 to 1942 compared to 38% for Kharkof, while in previous tests for 1932 to 1937 these varieties averaged approximately 5 and 45%, respectively. A total of 93 varieties had average infections lower than did Oro.

It is evident from these tests that a number of resistant selections have been obtained from hybrid combinations. Some of these are Hope × Turkey 1069, H44 × Minturki[2], Oro × Tenmarq, Martin × Tenmarq[3], Tenmarq × Minturki, and Blackhull × Oro. Several Turkey selections also have shown very low infection percentages.

The behavior of three new wheats recently increased and distributed should be noted. Comanche, a selection from the cross Oro × Tenmarq, had an average infection of bunt of 9%. Pawnee, a selection from Kawvale × Tenmarq, was included for 1 year and averaged 14% infection compared to 14% for Oro the same year. A third variety, Wichita, selected from Early Blackhull × Tenmarq developed more bunt than did Kharkof.

In the presentation of these data, the average percentages of infection for all stations in any one year are given. As a result, the true reaction of varieties and strains to individual physiologic races of the bunt organisms that may occur in different areas is masked. For example, as shown in the 1942 report, Oro developed approximately 7% bunt at Manhattan, Kans., but at Akron and Fort Collins, Colo., and at Bozeman, Mont., it had 55, 59, and 75%, respectively. Similar results were obtained with Comanche and other hybrid strains having Oro as one of the parents. These differences in reaction are explained by the absence of race L-8 in Kansas and the high prevalence of this race in collections made in Colorado and Montana. It should also be emphasized that the inoculum used in each test was a composite of several bunt collections. Relatively few chlamydospores of a particularly virulent race may have been present and, as a result of this dilution, the bunt severity from any one race no doubt was decreased. Thus, all of these results should be considered preliminary in nature and final tests with varieties and

TABLE 1.—*Summary of bunt infection of varieties and strains of winter wheat grown in the uniform winter wheat bunt nurseries in the Great Plains area, 1938–42.*

Variety or hybrid	C. I. No.	State No.	Percentage bunt infection						Percentage of Kharkof
			1938	1939	1940	1941	1942	Weighted average	
Hohenheimer	11458	—	Trace	—	—	—	—	Trace	Trace
Oro × Turkey-Florence	—	Pullman Sel. No. 9	—	—	—	Trace	Trace	Trace	Trace
Wheat × Rye (Meister)	11403	—	Trace	—	—	—	—	Trace	Trace
Hope × Turkey Sel.	11958	Kans. Sel. 383122	—	1	—	—	—	1	2.4
H44 × Minturki^2	12414	Minn. N.S.N. II–29–62	—	—	—	—	1	1	2.5
Kanred × Ridit	11840	Nebr. Sel. 31E–479	1	1	1	—	—	1	2.6
Relief	10082	—	Trace	1	1	3	1	1	2.6
Cheyenne Sel.	11666	Nebr. No. 1087	1	1	1	—	—	1	2.6
Hussar × Kanred	11989	Nebr. Sel. 31B–96	—	—	1	1	—	1	2.7
Hope × Turkey 1069	11968	Nebr. Sel. 363452	—	2	—	—	—	2	4.9
H44 × Minturki^2	—	Minn. N.S.N. II–29–68	—	—	—	—	2	2	5.0
Mont. 36–Beloglina × Kanred	12108	Mont. B.H. 31–143	—	—	—	—	2	2	5.0
Hope × Turkey 1069	11964	Nebr. Sel. 363401	—	1	1	4	—	2	5.1
Oro × Tenmarq	11729	Kans. Sel. 343255	2	2	—	—	—	2	5.1
Oro × Tenmarq	11807	Kans. Sel. 343638	2	3	1	—	—	2	5.1
Kanred × Minturki	11839	Nebr. Sel. 32J–788	1	3	2	—	—	2	5.1
Fulhard × Oro	11732	Kans. Sel. 343191	2	2	—	—	—	2	5.1
Hope × Hussar	11834	Kans. Sel. J352245	1	1	1	3	2	2	5.3
Marquillo × Minturki	—	Kans. Sel. B.N. 381231	—	—	—	2	1	2	5.3
Martin × Tenmarq^3	11825	Denton Sel. 50–35–8	2	—	—	—	—	2	5.4
Hope × Turkey 1069	11967	Nebr. Sel. 363392	—	3	—	—	—	3	7.3
Turkey Sel.	11963	Nebr. Sel. 4–CS–14	—	3	3	—	—	3	7.5
Turkey Sel.	11965	Nebr. Sel. 4–F–337	—	3	2	—	—	3	7.5
H44 × Minturki^2	—	Minn. N.S.N. II–29–72	—	—	—	—	3	3	7.5
Turkey 1069 × Tenmarq	11842	Nebr. Sel. 3252–9–8	2	4	—	—	—	3	7.7
Turkey Sel.	11841	Nebr. Sel. 4–CS–8	2	4	2	—	—	3	7.7
Oro × Tenmarq	11674	Kans. Sel. 342018	3	2	—	—	—	3	7.7

Tenmarq × Minturki	11833	Kans. Sel. 343228	2	3	3	—	—	3	7.7
Turkey Sel.	11962	Nebr. Sel. 4F–331	—	2	2	5	—	3	7.7
Hope × Turkey 1069	11966	Nebr. Sel. 363390	—	3	2	5	—	3	7.7
Martin × Tenmarq[3]	11824	Denton Sel. 50–35–6	2	5	3	—	—	3	7.7
Hussar × Kanred	11981	Nebr. Sel. 105	—	—	3	—	—	3	7.9
Hope × Turkey 1069	—	N. P. 151	—	—	—	3	2	3	7.9
Ridit × Quivira	—	Wd. No. 1177	—	—	—	4	2	3	7.9
Hussar	4843	—	10	2	1	3	1	3	7.9
Albit	8275	—	3	—	—	—	—	3	8.1
Kanred × Oro	11803	Denton Sel. 18–33–32	3	—	—	—	—	3	8.1
Minturki × Blackhull	11671	Nebr. No. 1089	3	—	—	—	—	3	8.1
Yogo × Oro	—	Mont. Sel. 5	—	—	—	—	4	4	10.0
Cache	11599	—	—	—	—	—	4	4	10.0
Turkey Sel.	11848	Nebr. Sel. 33764F–245	2	5	—	—	—	4	10.3
Martin × Tenmarq[3]	11823	Denton Sel. 50–33–128	2	4	6	—	—	4	10.3
Oro × Tenmarq	11830	Kans. Sel. 363596	6	5	2	—	—	4	10.3
Sherman × Kanred	11820	Nebr. Sel. 31B–263	2	6	—	—	—	4	10.3
Nebred	10094	Nebr. No. 1063	1	3	3	10	4	4	10.5
Hope × Turkey 1069	11988	Nebr. Sel. 363368	—	—	4	—	—	4	10.5
Tenmarq × Minturki	11982	Nebr. Sel. 23762	—	—	4	—	—	4	10.5
Hope × Turkey 1069	—	Kans. Sel. 383110	—	—	—	4	3	4	10.5
Martin × Tenmarq[3]	—	Denton Sel. 50–37–85	—	—	—	5	3	4	10.5
Turkey Sel.	11530	—	—	—	5	6	2	4	10.5
Martin × Tenmarq[3]	—	Denton Sel. 50–37–92	—	—	—	6	3	4	10.5
Turkey 1069 × Cheyenne	—	Nebr. Sel. 372765	—	—	—	6	3	4	10.5
Turkey Sel.	10016	Nebr. No. 1069	1	3	3	8	4	4	10.5
Martin × Tenmarq[3]	11805	Denton Sel. 50–33–63	1	6	3	7	—	4	10.5
Oro × Tenmarq	11832	Kans. Sel. 363615	4	—	—	—	—	4	10.8
Oro × Tenmarq	11828	Kans. Sel. 363595	4	—	—	—	—	4	10.8
Quivira × Fulhard-Oro	11811	Kans. Sel. 354152	4	—	—	—	—	4	10.8
Turkey 1069 × Quivira	—	Nebr. Sel. 372704	—	—	—	—	5	5	12.5
Blackhull × Oro	—	Woodward 37h1176–27	—	—	—	—	5	5	12.5
Blackhull × Oro	—	Woodward 36h922–59	—	—	—	—	5	5	12.5
Martin × Tenmarq[3]	11804	Denton Sel. 50–33–23	2	7	5	—	—	5	12.8
Oro × Tenmarq	11731	Kans. Sel. 343273	4	5	—	—	—	5	12.8
Ridit	6703	—	13	5	2	2	2	5	13.2
Turkey Sel.	11984	Nebr. Sel. 4CS–21	—	—	2	8	4	5	13.2

TABLE 1.—*Concluded.*

Variety or hybrid	C. I. No.	State No.	Percentage bunt infection						Percent-age of Kharkof
			1938	1939	1940	1941	1942	Weighted average	
Turkey 1069 × Cheyenne	11983	Nebr. Sel. 3256-13-8	—	—	5	—	—	5	13.2
Turkey 1069 × Quivira	11990	Nebr. Sel. 372707	—	—	3	8	4	5	13.2
Yogo	8033	———	3	5	4	10	4	5	13.2
Hope × Hussar	11836	Kans. Sel. 2343A-1-15	5	—	—	—	—	5	13.5
Quivira × Fulhard-Oro	11831	Kans. Sel. 354141	5	—	—	—	—	5	13.5
Beloglina × Hussar	11838	N. P. 134	5	—	—	—	—	5	13.5
Oro × Tenmarq	11829	Kans. Sel. 363602	5	—	—	—	—	5	13.5
Oro × C. I. 8034	———	Mont. Sel. 26	—	—	—	—	6	6	15.0
Blackhull × Oro	———	Woodward 37h1176-45	—	—	—	—	6	6	15.0
C. I. 8034 × Oro	———	Mont. Sel. 1	—	—	—	—	6	6	15.0
Blackhull × Oro	11961	Woodward No. 1176	—	6	3	8	5	6	15.4
Oro × Tenmarq	11728	Kans. Sel. 343249	5	7	—	—	—	6	15.4
Minturki	6155	———	4	4	3	9	8	6	15.8
Turkey Sel.	11985	Nebr. Sel. 4F-358	—	—	3	10	5	6	15.8
Turkey 1005 Sel.	———	Nebr. Sel. 4F-381	—	—	—	8	4	6	15.8
H44 × Minhardi	———	Minn. N.S.N. I-38-2	—	—	—	—	7	7	17.5
Quivira × Fulhard-Oro	11954	Kans. Sel. 354150	—	9	4	—	—	7	17.5
Blackhull × Oro	———	Woodward 36h931-2	—	—	—	—	7	7	17.5
Oro × Tenmarq	11672	Kans. Sel. 342003	7	—	—	—	—	7	18.9
Marquillo × Minturki	———	Kans. Sel. 37F.N.560	—	—	—	7	—	7	19.4
Marquillo × Oro	11955	Kans. Sel. 382960	—	8	7	—	—	8	20.0
H44 × Minturki[2]	———	Minn. N.S.N. II-29-65	—	—	—	—	8	8	20.0
Marquillo × Oro	———	Kans. Sel. 384146	—	—	—	—	8	8	20.0
Turkey 1069 × Tenmarq	———	Nebr. Sel. 372636	—	—	—	11	5	8	21.1
Marquillo × Oro	11980	Kans. Sel. 383487	—	—	6	10	—	8	21.6
Marquillo × Oro	11851	Kans. Sel. 382963	—	9	6	11	—	9	23.1
Comanche	11673	Kans. No. 2729	6	6	5	16	10	9	23.7
Quivira × Fulhard-Oro	———	Kans. Sel. 396242	—	—	—	—	10	10	25.0

Oro × Tenmarq	11827	Kans. Sel. 363594	7	12	—	—	—	10	25.6
Marquillo × Oro	11957	Kans. Sel. 37F.N.2649	—	11	—	—	—	11	26.8
Oro	8220	——	6	10	7	17	14	11	28.9
Hope × Turkey 1069	11986	Nebr. Sel. 363442	—	—	11	—	—	11	28.9
Tenmarq × Oro	——	Denton Sel. 71-37-38	—	—	—	11	10	11	28.9
Marquillo × Oro	11979	Kans. Sel. 383483	—	—	7	14	—	11	29.7
Marquillo × Oro	11978	Kans. Sel. 383475	—	—	8	14	—	11	29.7
Turkey 1069 × Quivira	——	Nebr. Sel. 372698	—	—	—	11	—	11	30.6
Marquillo × Oro	——	Kans. Sel. 394448	—	—	—	11	—	11	30.6
Tenmarq × Oro	——	Denton Sel. 70-38-44	—	—	—	12	—	12	33.3
Hope × Turkey 1069	11987	N. P. 143	—	—	13	—	—	13	34.2
Pawnee	11669	Nebr. No. 1086	—	—	—	—	14	14	35.0
Marquillo × Minturki	——	Kans. Sel. 37F.N.612-3	—	—	—	13	—	13	36.1
Turkey 1069 × Quivira	——	Nebr. Sel. 372694	—	—	—	13	—	13	36.1
Marquillo × Oro	——	Kans. Sel. 383476	—	—	—	13	—	13	36.1
Hope × Hussar	11835	Kans. Sel. G2343A3-38	15	—	—	—	—	15	40.5
Hope × Kawvale	11960	Kans. Sel. 383014	—	19	—	—	—	19	46.3
Tenmarq × Oro	——	Denton Sel. 70-38-25	—	—	—	17	—	17	47.2
Hope × Kawvale	11959	Kans. Sel. 383008	—	17	22	—	—	20	50.0
Turkey 1069 × Cheyenne	11991	Nebr. Sel. 372722	—	—	21	—	—	21	55.3
Oro × Marquillo-Tenmarq	——	Kans. Sel. 402404	—	—	—	—	23	23	57.5
Kharkof × Reliance-Hope	——	Woodward 36h4496-11	—	—	—	23	—	23	63.9
Hope × Kawvale	11826	Kans. Sel. J-361615	24	—	—	—	—	24	64.9
Marquillo × Tenmarq	——	Kans. Sel. 384012	—	—	—	25	—	25	69.4
Hope × Kawvale	11837	Kans. Sel. J352886	28	—	—	—	—	28	75.7
Kharkof	1442	——	37	41	38	36	40	38	100.0
Cheyenne	8885	——	38	46	53	39	43	44	115.8
Wichita	11952	Kans. No. 2739	—	—	—	56	43	49	128.9
Quivira	8886	——	50	57	45	52	—	51	134.2
Chiefkan	11754	——	—	59	65	67	68	65	166.7
Red Chief	12109	——	—	—	—	—	86	86	215.0

TABLE 2.—*Summary of reaction of varieties and strains of winter wheat to dwarf bunt when grown at Logan, Utah, 1941 and 1942.*

Variety or hybrid	C. I. No.	State No.	Percentage bunt infection			Percentage of Kharkof
			1941	1942	Average	
Hussar × Kanred	11989	Nebr. Sel. 31B–96	0	—	0	0
Martin × Tenmarq[3]	—	Denton Sel. 50–37–92	1	0	1	1.7
Turkey Sel.	11530	—	2	0	1	1.7
Martin × Tenmarq[3]	11805	Denton Sel. 50–33–63	1	—	1	2.7
Relief	10082	—	2	1	2	3.4
Ridit × Quivira	—	Woodward Sel. 1177	2	2	2	3.4
Martin × Tenmarq[3]	—	Denton Sel. 50–37–85	2	2	2	3.4
Hope × Hussar	11834	Kans. Sel. J-352245	3	2	3	5.1
Oro × Turkey-Florence	—	Pullman Sel. No. 9	0	8	4	6.8
Hussar	4843	—	7	0	4	6.8
Kharkof × Reliance-Hope	—	Woodward Sel. 36h4496–11	3	—	3	8.1
Blackhull × Oro	—	Woodward Sel. 36h931–2	—	8	8	10.0
Ridit	6703	—	4	7	6	10.2
Blackhull × Oro	11961	Woodward No. 1176	6	10	8	13.6
Comanche	11673	Kans. No. 2729	6	15	11	18.6
Cache	11599	—	—	17	17	21.3
Blackhull × Oro	—	Woodward Sel. 37h1176–45	—	18	18	22.5
Marquillo × Oro	11851	Kans. Sel. 382963	9	—	9	24.3
Tenmarq × Oro	—	Denton Sel. 70–38–25	9	—	9	24.3
Turkey Sel.	11962	Nebr. Sel. 4F–331	9	—	9	24.3
H44 × Minturki[2]	—	Minn. N. S. N. II–29–72	—	20	20	25.0
Pawnee	11669	Nebr. No. 1086	—	23	23	28.8
Marquillo × Minturki	—	Kans. Sel. 37 F.N. 560	11	—	11	29.7
Yogo × Oro	—	Montana Sel. 5	—	30	30	37.5
Marquillo × Oro	—	Kans. Sel. 383476	14	—	14	37.8
Tenmarq × Oro	—	Denton Sel. 70–37–38	6	40	23	39.0
Mont. 36–Beloglina × Kanred	12108	Mont. B.H.–31–143	—	33	33	41.3
Blackhull × Oro	—	Woodward Sel. 36h922–59	—	33	33	41.3
Tenmarq × Oro	—	Denton Sel. 70–38–44	16	—	16	43.2
H44 × Minturki[2]	—	Minn. N.S.N. II–29–68	—	35	35	43.8
Yogo	8033	—	11	40	26	44.1

Turkey 1069 × Tenmarq	——	Nebr. Sel. 372636	10	43	27	45.8
Oro	8220	——	9	48	29	49.2
Marquillo × Oro	11978	Kans. Sel. 383475	19	—	19	51.4
Marquillo × Minturki	——	Kans. Sel. 37F.N.612–3	20	—	20	54.1
Hope × Turkey 1069	11964	Nebr. Sel. 363401	20	—	20	54.1
Cheyenne	8885	——	16	48	32	54.2
C. I. 8034 × Oro	——	Montana Sel. 1	—	45	45	56.3
Turkey 1069 × Quivira	11990	Nebr. Sel. 372707	10	58	34	57.6
Marquillo × Oro	11979	Kans. Sel. 383483	22	—	22	59.5
Quivira	8886	——	22	—	22	59.5
Quivira × Fulhard-Oro	——	Kans. Sel. 396242	—	48	48	60.0
Turkey Sel	11984	Nebr. Sel. 4-CS-21	21	50	36	61.0
Turkey 1069 × Quivira	——	Nebr. Sel. 372698	23	—	23	62.2
Chiefkan	11754	——	20	53	37	62.7
Marquillo × Minturki	——	Kans. Sel. B.N. 381231	13	65	39	66.1
Oro × C. I. 8034	——	Montana Sel. 26	—	53	53	66.3
H44 × Minturki²	12414	Minn. N.S.N. II–29–62	—	53	53	66.3
H44 × Minturki²	——	Minn. N.S.N. II–29–65	—	53	53	66.3
Hope × Turkey 1069	11966	Nebr. Sel. 363390	25	—	25	67.6
Blackhull × Oro	——	Woodward 37h1176–27	—	55	55	68.8
Marquillo × Oro	——	Kans. Sel. 384146	—	55	55	68.8
Minturki	6155	——	19	63	41	69.5
Wichita	11952	Kans. No. 2739	14	70	42	71.2
Red Chief	12109	——	—	58	58	72.5
Turkey 1005 Sel	——	Nebr. Sel. 4F–381	33	53	43	72.9
Hope × Turkey 1069	——	Kans. Sel. 383110	25	63	44	74.6
Nebred	10094	——	23	65	44	74.6
Marquillo × Oro	11980	Kans. Sel. 383487	29	—	29	78.4
Marquillo × Tenmarq	——	Kans. Sel. 384012	29	—	29	78.4
Hope × Turkey 1069	——	N. P. Sel. 151	33	60	47	79.7
Turkey 1069 × Quivira	——	Nebr. Sel. 372704	—	65	65	81.3
Turkey Sel	10016	——	46	55	51	86.4
Turkey 1069 × Quivira	——	Nebr. Sel. 372694	33	—	33	89.2
Oro × Marquillo-Tenmarq	——	Kans. Sel. 402404	—	73	73	91.3
Turkey 1069 × Cheyenne	——	Nebr. Sel. 372765	44	65	55	93.2
H44 × Minhardi	——	Minn. Sel. N.S.N. I–38–2	—	75	75	93.8
Turkey Sel	11985	Nebr. Sel. 4-F-358	58	53	56	94.9
Kharkof	1442	——	37	80	59	100.0
Marquillo × Oro	——	Kans. Sel. 394448	52	—	52	140.5

strains that appear here to be resistant should be made with individual bunt races before final conclusions are drawn.

Dwarf bunt of whear has not been found in the Great Plains area. In a search for factors for resistance, however, the varieties and strains included in the hard red winter wheat nurseries have been tested at Logan, Utah. Data obtained in 1937 have already been published[5] and those obtained in 1941 and 1942 are presented in Table 2. In these tests both Martin (C. I. 4463) and Hussar (C. I. 4843) and certain hybrids involving one or the other as parents were highly resistant. One strain, Hussar × Kanred (C. I. 11989), had no infection the year it was tested and three other selections had averages of only 1%. Relief (C. I. 10082) and Ridit (C. I. 6703), in addition to the above wheats, are included among 14 varieties and selections having less than 10% infection in these tests. Holton and Suneson[6] have determined the reaction of varieties and selections of winter wheats at several stations in the western region. A few of these wheats were used in both series of tests reported here. The results reported in Table 2 are in agreement with those reported by Holton and Suneson, except for the reaction of Minturki, which in the present tests showed 63% infection at Logan in 1942.

SUMMARY

A large number of varieties and strains of hard red winter wheat have been tested for bunt reaction at several stations in the Great Plains and at Kearneysville, W. Va.; Beltsville, Md.; and Logan, Utah. The inoculum used was a composite of collections of *Tilletia foetida* and *T. caries* obtained from fields selected at random throughout the state in which the test or tests were made.

No variety was free from bunt in all tests, but a number showed considerable resistance. Selections from such crosses as Hope × Turkey 1069, H44 × Minturki[2], Oro × Tenmarq, Martin × Tenmarq, and Blackhull × Oro had a rather high degree of resistance.

Since only bulk inoculum was used, these tests should be considered as preliminary. The more resistant varieties are being tested to known races.

When tested with the dwarf bunt organism at Logan, Utah, four strains were as resistant as Relief and eight as resistant as Hussar. Most of these wheats had Hussar, Martin, or Ridit as one parent.

[5]See footnote 3.

[6]HOLTON, C. S., and SUNESON, C. A. Wheat varietal reaction to dwarf bunt in the western region of the United States. Jour. Amer. Soc. Agron., 35:579–583. 1943.

EFFECT OF MANURE, MOISTURE, AND MECHANICAL INJURY ON THE HYDROCYANIC ACID CONTENT OF SORGHUM[1]

C. J. Franzke and A. N. Hume[2]

THE amount of hydrocyanic acid occurring in strains of sorghum is subject to modification by changes in environment, such as weather, soil fertility, and kind and amount of fertilizers. Also, it may be modified by injuries from a variety of causes, such as wind, hail, trampling by animals, insects, crop diseases, or by farm machinery.

The purpose of the present investigation was to determine the effect of manure, moisture, and mechanical injuries on the hydrocyanic acid content of sorghum. These are presented under two headings, first, the effects of stall manure applied on two soil types at three moisture levels on the hydrocyanic acid in sorghum strains, and second, artificial injury to sorghum strains and its effect upon the hydrocyanic acid content.

LITERATURE

Only publications having a direct bearing on modification of growth and consequent hydrocyanic acid in sorghum are cited. Brunnich (2)[3] listed a large number of "conflicting statements and theories" about conditions under which sorghums may become poisonous, as variations in maturity, rainfall, drought, frost, insect damage, molds or fungi, fertilizers, temperature, and humidity. A summary of factors influencing hydrocyanic acid in sorghums has been presented by Couch (4).

Peters, *et al.* (9), Francis (5), and Vinall (11) stated that growth arrested by drought presents a very favorable condition for the elaboration of the poison. Willaman and West (12), Coleman and Robertson (3), Leemann(8), and Couch (4) cited instances where climate and soil influenced hydrocyanic acid in sorghum.

Hogg and Ahlgren (7), after growing 10 lines of Sudan grass at several experiment stations in the United States and Canada, concluded that the hydrocyanic acid content is profoundly influenced by soil and climate. They further state that temperature is important in determining the level of hydrocyanic acid while rainfall and sunshine affected no significant correlation.

Willaman and West (12) found that sorghum plants grown under inadequate moisture conditions were higher in hydrocyanic acid than plants grown under more favorable conditions. Franzke, *et al.* (6) found that sorghum plants grown under high soil moisture were lower in hydrocyanic acid than those grown under droughty conditions. Hogg and Ahlgren (7) found that hydrocyanic acid of Sudan grass increased as the moisture content of the soil decreased.

Soil fertility apparently has an effect upon hydrocyanic acid content in sorghums. Willaman and West (12) found that heavy nitrogen fertilization had an effect on hydrocyanic acid of Sudan grass. Pinckney (10) demonstrated that size, color, and prussic acid content of sorghum plants were affected by adding different amounts of sodium nitrate to three Minnesota soils low in nitrogen. Brunnich (2) and Boyd, *et al.* (1) found that addition of nitrate to the soil increased hydrocyanic acid. Franzke, *et al.* (6) and Boyd, *et al.* (1) found that applications of phosphorus reduced the hydrocyanic acid. Franzke, *et al.* (6) noted that, under field conditions, barnyard manure decreased the hydrocyanic acid but sweetclover plowed under as green manure caused an increase.

Franzke, *et al.* (6), working on forage sorghum, and Hogg and Ahlgren (7),

[1]Journal Paper No. 194 South Dakota Agricultural Experiment Station, Brookings, S. D. Received for publication October 31, 1944.

[2]Assistant Agronomist and Agronomist, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 531.

working on Sudan grass, state, "that hydrocyanic acid content is a heritable character and also that hydrocyanic acid in selected strains is modified by changes in environment and soil conditions".

EFFECTS OF MANURE AND DIFFERENT MOISTURE LEVELS ON HYDROCYANIC ACID IN SORGHUM

MATERIAL AND METHODS

Ninety-six 2-gallon stone jars were divided into two series of 48 each. One series was filled with Barnes sandy loam soil from a continuous wheat plot at Brookings Main Station; the other with Orman clay from a continuous wheat plot at Cottonwood Substation. Wheat had grown continuously for 15 years at each location. No fertilizer had been added to either plot. The Barnes sandy loam will be hereafter known as series I and the Orman clay as series II.

Series I and II were each divided into two groups of 24 jars. One group in each of the series was treated with stall manure. An application equivalent to 10 tons per acre was calculated on the basis of the surface area of each jar and thoroughly mixed with the soil. The other group in each series was left untreated.

The treated and untreated group of series I and II were again divided into two sub-groups of 12 jars each. One sub-group was planted with low hydrocyanic acid sorghum strain No. 39 and the other sub-group with high hydrocyanic acid strain No. 19. Both strains are very similar in maturity and vegetative growth and are forage sorghum types selected from the Dakota Amber variety.

Each sub-group of series I and II was then divided into six manured and six unmanured jars. Duplicates of treated and untreated jars of each sub-group were supplied with 15, 25, and 35% of moisture. Air-dry weights of the soil were previously determined and percentages of moisture were maintained at the given levels with addition of distilled water three times per week.

The first planting of sorghum was made January 28, 1939. Thirty sorghum seeds were planted in each of the 96 jars, consisting of 10 hills with three seeds each. The seedlings were thinned to one plant per hill, leaving 10 plants to grow in each jar. In the course of the experiment the jars were rotated and randomized.

On March 22 when the plants were heading each group of series I and II was harvested separately, tagged, and properly labeled. The leaves were stripped from the stalk and midribs of the leaves removed before cutting the leaf blades into smaller portions. The leaves from each jar were cut into pieces approximately ½ inch in length and the finely cut portions thoroughly mixed by hand before further sampling. Samples were weighed out for moisture and hydrocyanic acid determination. Determinations of the hydrocyanic acid were made in duplicate by the method described by Franzke, *et al.* (6) and the content of hydrocyanic acid reported in parts per million of dry matter.

After harvesting the plants for analysis, the stubble remaining was removed from all jars in series I and II. An additional application equivalent to 10 tons per acre of stall manure was applied March 22 and thoroughly mixed into the soil of all the jars previously treated. April 8, the jars were replanted with sorghum exactly as before. The second run was completed June 11 when the sorghum plants were heading. The handling of the plants after harvest and the hydrocyanic acid and moisture determinations were made similarly to those of the first run.

EXPERIMENTAL RESULTS

After the completion of analyses of hydrocyanic acid in the plants of the two sorghum strains grown on series I and series II, a careful comparison of the results from the first and second run was made. It appeared that the trends of the results were the same. Accordingly, an average of the p.p.m. of hydrocyanic acid in the strains from corresponding treatments in the two runs was calculated and is reported in Table 1.

The hydrocyanic acid content was higher for strains 39 and 19 produced on series I than on series II. This is true for both sorghum strains irrespective of whether manure was applied.

TABLE 1.—*Average (first and second run) hydrocyanic acid content in p.p.m. in sorghum strains grown on two soil types with and without manure at three moisture levels.*

Moisture, %	Strain 39				Strain 19			
	Series I, Barnes sandy loam		Series II, Orman clay		Series I, Barnes sandy loam		Series II, Orman clay	
	No manure	10 tons manure per acre	No manure	10 tons manure per acre	No manure	10 tons manure per acre	No manure	10 tons manure per acre
15	400	370	397	283	2,358	1,625	1,903	1,498
25	323	282	201	172	709	557	699	582
35	175	139	170	100	212	116	267	208
Average....	299.3	263.7	256.0	185.0	1,093.0	766.0	956.3	762.7

The hydrocyanic acid content in the sorghum strains decreased as the soil moisture level increased. This decrease in hydrocyanic acid content occurred in both sorghum strains grown on series I and II with and without manure. Soil moisture apparently plays an important role in determining the level of hydrocyanic acid in sorghum plants.

The summary on relation between rate of growth of the sorghum plants and the hydrocyanic acid content is shown in Fig. 1.

It may be observed that the application of stall manure to soil of sorghum cultures, under the conditions of this experiment, was attended by reduction in content of hydrocyanic acid in the leaves of sorghum plants.

The application of stall manure produced increases in growth of the plants in which the reduction in hydrocyanic acid occurred. These increases in growth were produced in two separate strains of sorghum and on two representative soil types which may be assumed to represent a wide range of conditions actually encountered in sorghum culture.

The applications of stall manure were made in comparison at three progressive soil-moisture levels. The increases in soil moisture were attended with decreases in content of hydrocyanic acid. These decreases also occurred in connection with increase in growth of plants. The increase of growth due to increase of soil moisture was always less on untreated soils. The application of stall manure was evidently effective first in inducing increased growth, and also in inducing corresponding reduction in content of hydrocyanic acid in the leaves of sorghum plants when soil moisture was available.

MECHANICAL INJURY APPLIED TO SORGHUM PLANTS GROWN UNDER FIELD CONDITION AND ITS EFFECT UPON THE HYDROCYANIC ACID CONTENT IN SORGHUM STRAINS

MATERIAL AND METHODS

In two separate seasons, sorghum plants from pure lines were subjected to mechanical injury. The injury was applied to Dakota Amber strains originally

selected for hydrocyanic acid content. Strain 1 is a high hydrocyanic acid selection which has growth characters and maturity similar to those of strains 19 and 39 described above. Strain 15 is likewise a high hydrocyanic acid selection, but the leaves are not typical Dakota Amber leaves. They are broad, thick, leathery in texture, and dark rich green in color.

The injury applied to the strains was performed when the plants were at the nine-leaf stage. The manner of making the injury was as follows: A 2-ounce ball-hammer was raised approximately 9 inches above the point on the stem of the

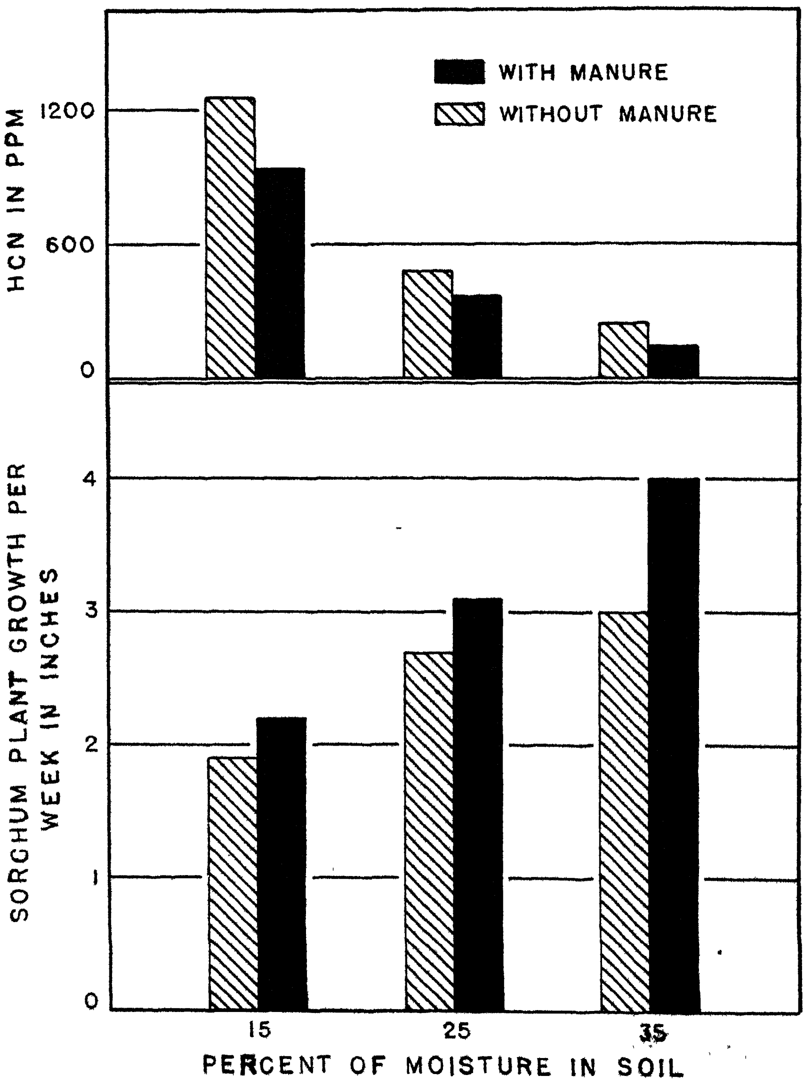

FIG. 1.—Hydrocyanic acid content and average weekly growth of sorghum plants from manured and unmanured soil cultures at three moisture levels.

plant to be injured. The plant was held firmly by placing the hand on the opposite side at the point to be injured. The hammer was allowed to fall by its own weight and strike the stem at the given point. Each plant subjected to injury was struck eight times, first on one side of the stem, then eight times on the opposite side. The method of sampling and handling of material for hydrocyanic acid and moisture determinations and reporting of results was made in the same manner as described above.

1937 RESULTS

Only preliminary observations were obtained in 1937, since a limited number of plants were available. The results are presented in Table 2.

TABLE 2.—*Effect of mechanical injury upon hydrocyanic acid content in sorghum plants, 1937.*

Strain No.	Stage	Number of days from injury	Plant characters	Height, inches	Hydrocyanic acid, p.p.m.
19	9 leaf	Check	Normal	28¾	3,480
19	9 leaf	3	Leaves rolled	20	2,970
19	9 leaf	Check	Normal	31¾	4,010
19	9 leaf	4	Leaves rolled and tip burning	20¼	3,620
1	Shooting	Check	Normal	40	3,320
1	9 leaf	5	Leaves rolled and badly tipburned	22	3,890
1	Shooting	Check	Normal	42¾	3,700
1	9 leaf	6	Leaves rolled and badly tipburned	21	4,240
39	Heading	Check	Normal	43½	320
39*	9 leaf	10	Leaves badly tipburned and new side growth 1½ in.	28½	403
39	Fertilized	Check	Normal	49	230
39*	9 leaf	19	Leaves badly tipburned and new side growth 5½ in.	29	420

*Side growth out from leaf and stem axile.

In all of the injured plants, every injured point on the stem turned light green in color and dry in texture, while the leaves developed signs of tip-burn. This change on the stems was easy to detect on the day following the injury.

Comparison of hydrocyanic acid in the leaf samples taken either 3 or 4 days after injury showed that the content of hydrocyanic acid was greater in normal than in injured plants. After 4 days from injury, however, the hydrocyanic acid content of injured plants was higher than that of normal plants.

Determinations were made of hydrocyanic acid in leaves of side branches. These side branches developed within a period of 10 days on injured plants of strain 39. The hydrocyanic acid content in the leaves of these side branches was 980 p.p.m., which is more than twice the amount found in the original leaves of the injured plants.

1939 RESULTS

In 1939, two 4-rod row plots of each strain of sorghum 19 and 15 were planted in the field. Before artificial injuries were applied, the plants in the rows were thinned in a manner to leave a selection of the most uniform in height and stage of growth. At the time of injury, the plants were all at the "nine-leaf stage". Artificial injury was performed in 1939 with the 2-ounce ball hammer as described previously.

Leaf-rolling on injured plants occurred as in 1937 but was less noticeable in 1939. The injuries to the stems of plants at the points struck by the hammer, however, were very pronounced.

The content of hydrocyanic acid in strain 19 the first week after injury showed a greater increase than that for strain 15 (Fig. 2). After the first week, the injured plants of both strains had a higher content of hydrocyanic acid than the uninjured plants.

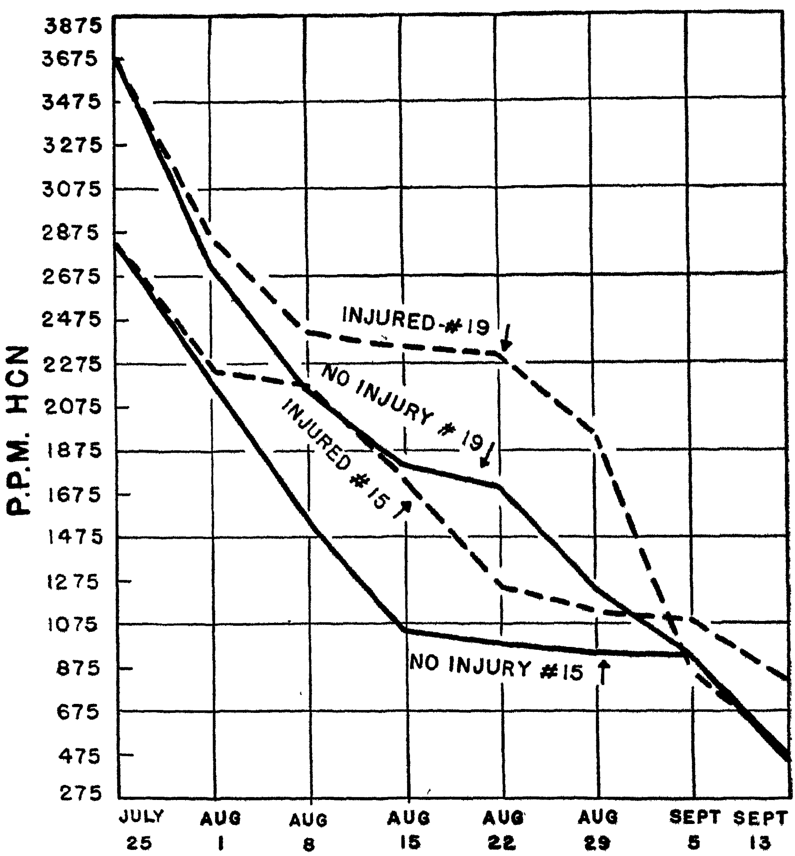

FIG. 2.—Content of hydrocyanic acid in mechanically injured and uninjured sorguhm plants of strains 19 and 15, 1939.

In strain 19, the mean content of hydrocyanic acid in the uninjured plants was 1,836 p.p.m.; in the mechanically injured plants it was 2,112 p.p.m. Strain 15 likewise showed a higher hydrocyanic acid content for the mechanically injured plants. The hydrocyanic acid content for the uninjured plants was 1,364 p.p.m. and for the injured plants 1,655 p.p.m.

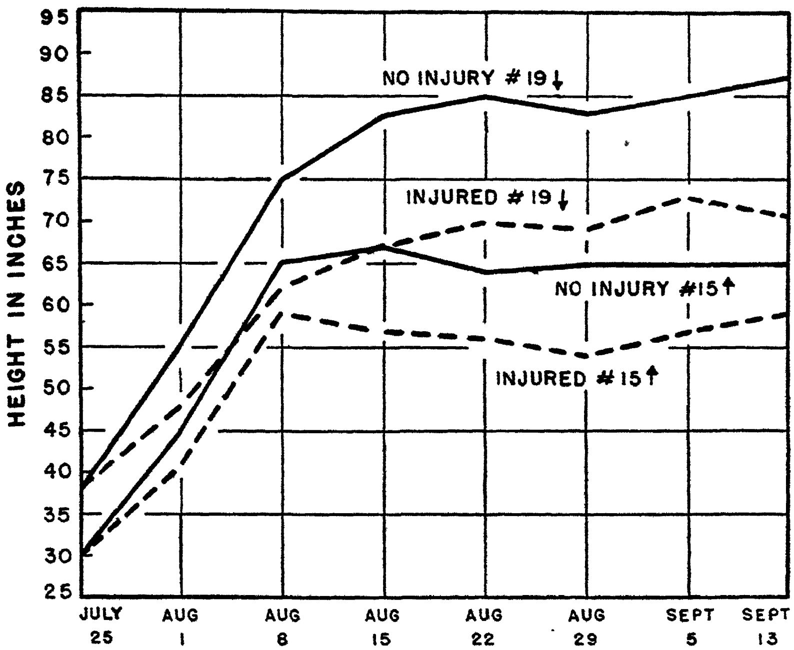

FIG. 3.—Weekly growth in inches for mechanically injured and uninjured sorghum plants of strains 19 and 15, 1939.

The difference between hydrocyanic acid in the injured and uninjured plants was almost negligible the first week after injury. Thereafter, the hydrocyanic acid content of the injured plants grew steadily greater in comparison with that of uninjured plants reaching a maximum difference on August 29 for strain 19 and on August 15 for strain 15 (Fig. 2). This difference became less as the plants approached maturity on September 5.

The weekly growth for the two strains, expressed as height in inches, is shown in Fig. 3. The continued lag in the rate of growth for injured plants was apparent throughout the sampling periods. Strain 19 showed a greater retarded growth following injury from July 25 to August 8 than strain 15 (Fig. 3). After August 8, a fairly uniform difference in height was maintained between injured and uninjured plants of both strains throughout the remainder of the sampling periods. The mean height for the uninjured plants of strain 19 was 72.7 inches and for the injured plants 61.1 inches. Strain 15 likewise showed a similar difference in the height of the uninjured

and injured plants, the mean heights being 57.9 and 51.2 inches, respectively.

Comparison of the heights of plants (Fig. 3) with the hydrocyanic acid content (Fig. 2) indicates that retarding the rate of growth by mechanical injury was accompanied by an increase in the hydrocyanic acid content. The maximum difference in the height of injured and uninjured plants occurred August 15 and 22 for strains 15 and 19, respectively.

It is apparent from Fig. 4 that growth stage was retarded in the injured as compared with uninjured plants. This comparative lag

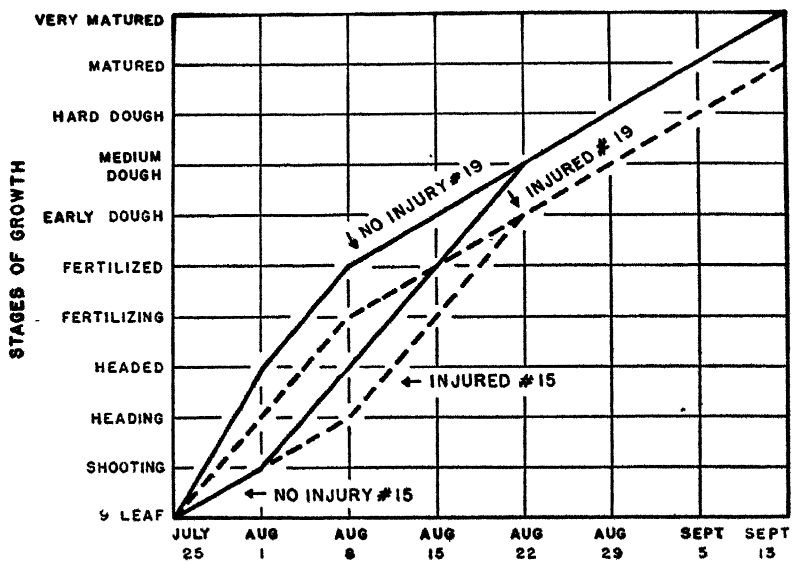

FIG. 4.—Mechanical injury and its effect upon growth development in sorghum plants of strains 19 and 15, 1939.

in the stage of development for the injured plants continued throughout the season as long as samples were taken. Strain 15 showed no immediate effect from injury the first week thereafter. It became apparent the second week. Strain 19 showed immediate effect of injury to growth.

SUMMARY AND CONCLUSIONS

1. The application of stall manure to sorghum cultures grown on two soil types under greenhouse conditions resulted in a decreased hydrocyanic acid content as compared with unmanured cultures.

2. Increase in soil moisture levels produced a decreased hydrocyanic acid content in sorghum plants.

3. The greater decrease in the hydrocyanic acid content in sorghum plants occurred where the application of manure and increase in soil moisture levels were combined.

4. The application of stall manure and increase in soil moisture levels produced an increase in growth of the sorghum plants. This increased growth was always accompanied by a decrease in hydrocyanic acid content.

5. The maximum reduction in the content of hydrocyanic acid resulting from application of manure to the soil types as compared with unmanured cultures occurred where the soil moisture level was the lowest (15%).

6. The slower rate of growth or a lag in plant development which was caused by mechanical injury to sorghum plants was accompanied by an increase in hydrocyanic acid content as compared with uninjured plants.

7. New growth which developed as side branches in the leaf axile on injured plants was found to contain more than twice as much hydrocyanic acid as compared to the original leaves of the injured plants.

8. Factors which favor normal growth in sorghum strains, such as soil type, application of stall manure, adequate moisture, and freedom from mechanical injury, resulted in a lower hydrocyanic acid content in sorghum plants. Injured or stunted sorghum plants where growth had been retarded, maintained a higher level of hydrocyanic acid for a longer period than plants where the growth was rapid and normal.

LITERATURE CITED

1. BOYD, F. T., AAMODT, O. S., BOHSTED, T. G., and TRUOG, E. Sudan grass management for control of cyanide poisoning. Jour. Amer. Soc. Agron., 30:569–582. 1938.
2. BRUNNICH, I. C. Hydrocyanic acid in fodder plants. Jour. Chem. Soc., 28:788–796. 1903.
3. COLEMAN, O. H., and ROBERTSON, D. W. Preliminary report of inheritance of differential ability of inbred lines of Sudan grass to produce HCN. Colo. Agr. Exp. Sta. Tech. Bul. 24. 1938.
4. COUCH, JAMES F. Poisoning of livestock by plants that produce hydrocyanic acid. U.S.D.A. Leaflet 88. 1932.
5. FRANCIS, C. K. Poisoning of livestock while feeding on plants of the sorghum group. Okla. Agr. Exp. Sta. Cir. 38. 1915.
6. FRANZKE, C. J. PUHR, LEO F., and HUME, A. N. A study of sorghum with reference to the content of HCN. S. D. Agr. Exp. Sta. Tech. Bul. 1. 1939.
7. HOGG, PETER G., and AHLGREN, H. L. Environmental, breeding, and inheritance studies of hydrocyanic acid in *Sorghum vulgare* Var. *Sudanense*. Jour. Agr. Res., 67:195–210. 1943.
8. LEEMANN, A. C. Hydrocyanic acid in grasses. Ond. Jour. Vet. Sci. and An. Ind., 5:97–136. 1936.
9. PETERS, A. T., SLADE, H. B., and AVERY, SAMUEL. Poisoning of cattle by common sorghum and kafir corn. Nebr. Agr. Exp. Sta. Bul. 77. 1903.
10. PINCKNEY, R. M. Effects of nitrate applications upon the hydrocyanic acid content of sorghum. Jour. Agr. Res., 27:717–723. 1924.
11. VINALL, H. W. A study of the literature concerning poisoning of cattle by prussic acid in sorghum, Sudan grass, and Johnson grass. Jour. Amer. Soc. Agron., 13:267–280. 1921.
12. WILLAMAN, J. J., and WEST, R. M. Effects of climatic factors on the hydrocyanic acid in sorghum. Jour. Agr. Res., 6:261–272. 1916.

THE NATURE OF THE PHOSPHATES DISSOLVED BY VARIOUS SOIL EXTRACTANTS[1]

G. S. FRAPS AND J. F. FUDGE[2]

SEVERAL different extractants and procedures have been proposed for the estimation of easily soluble phosphoric acid in soils. The strength and nature of the extractant used, the period of extraction, and the ratio of soil to extractant have differed widely.

Peech and English (10)[3] have shown recently that the quantities of phosphoric acid dissolved from a number of New York soils by the acetic acid extractant proposed by Morgan (9) were much smaller than those dissolved by the 0.002 N sulfuric acid proposed by Truog (14). It was thought that a study of the solubility of different phosphates and of phosphate fixation by the soil might furnish information concerning the nature of the phosphates dissolved from soils by different extractants.

METHODS AND MATERIALS

Extractants used included 0.2 N nitric acid (4, 5), 0.75 N hydrochloric acid (13), 0.002 N sulfuric acid buffered with 0.3% ammonium sulfate (12), and 0.52 N acetic acid in 10% sodium acetate (9, 10). The procedures proposed for the use of these extractants differed in a number of important respects, as shown in Table 1. In addition to the procedures as proposed, 5-minute periods of extraction with 0.2 N nitric acid and 0.75 N hydrochloric acid were used in some cases. In one procedure (A, Table 1) using 0.2 N nitric acid (4), phosphoric acid was determined volumetrically. In all other procedures, phosphoric acid was determined colorimetrically by a modified Deniges method (4, 7), with use of a Klett-Summerson photoelectric colorimeter equipped with a No. 62 filter and a 20-mm or 40-mm cell. Shaking of the suspensions was done by hand for the 1-minute and 5-minute periods, and by an end-over-end shaking machine for the 30-minute periods.

The solubility of a number of phosphates in the various extractants was estimated with quantities of the phosphates calculated from their analyses to contain either 4 milligrams or 8 milligrams of total phosphoric acid (P_2O_5), and with volumes of the different extractants which would be used for 40 grams of soil. Phosphoric acid in the different phosphates was thus equivalent to 100 p.p.m. or 200 p.p.m. on the soil basis. The easily soluble phosphoric acid in a number of soils was determined with the use of the procedures as proposed by the

TABLE 1.—*Comparison of essential points in the various methods.*

	0.2 N nitric acid		0.75 N hydrochloric acid	0.002 N sulfuric acid	0.52 N acetic acid
	A	B			
pH of extractant	<1	<1	<1	3.0	4.8
Weight of soil used, grams	200	10	2.5	2.0	10
Volume of extractant, cc	2,000	100	10	200	50
Ratio of soil to solvent	10	10	4	100	5
Volume of N acid to 100 grams of soil	200	200	300	40	260
Time of extraction, minutes	300	30	1	30	30

[1]Contribution from the Division of Chemistry, Texas Agricultural Experiment Station, College Station, Texas. Received for publication December 1, 1944.

[2]Chief and Chemist, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 541.

different workers, except that the 0.75 N hydrochloric acid method was modified to give quantitative results with the use of 2.5 grams of soil.

SOLUBILITY OF PHOSPHATES

Hydrated and anhydrous calcium phosphate, calcium hydroxyphosphate, fused rock phosphate, and basic slag were almost completely soluble in all solvents used and the results were not tabulated. The solubility of a number of other phosphates is shown in Table 2 for the amounts of the phosphates equivalent to 200 p.p.m. of total phosphoric acid. Work was done with 100 p.p.m., but the results are not tabulated since they were practically the same as with 200 p.p.m. Calcined phosphate, "colloidal" phosphate (also called waste-pond phosphate and, by the A.O.A.C. definition, soft rock phosphate with colloidal clay), Tennessee brown rock phosphate (A), and another rock phosphate (B) of unknown origin were almost completely soluble in 0.2 N nitric acid, 0.75 N hydrochloric acid and, with the exception of rock phosphate B (only 44% soluble), in 0.002 N sulfuric acid. Their solubility in acetic acid was much lower. Fluorapatite was less soluble than other calcium phosphates with a 5-minute extraction with 0.2 N nitric acid (63% soluble) or with a 1-minute period of extraction with 0.75 N hydrochloric acid (54%), whereas it was completely soluble in 0.2 N nitric acid after a 30-minute extraction and 35% soluble in 0.75 N hydrochloric acid after a 5-minute extraction. After a 30-minute extraction, only 25% of the phosphoric acid in fluorapatite was soluble in 0.002 N sulfuric acid and only 3% in 0.52 N acetic acid. The phosphoric acid in the natural iron and ammonium phosphate had a low solubility in all extractants.

TABLE 2.—*Solubility of different phosphates in various extractants.*

Extractant	Period of extraction, minutes	Calcined phosphate	Colloidal phosphate	Rock phosphate A	Rock phosphate B	Fluorapatite	Natural Fe and Al phosphate
Total phosphoric acid, %		26.73	20.69	33.86	32.10	37.70	42.34
		Percentage Dissolved					
0.2 N nitric acid....	5	97	98	97	95	63	2
0.2 N nitric acid....	30	95	83	100	90	100	3
0.75 N hydrochloric acid............	1	91	86	90	92	54	2
0.75 N hydrochloric acid............	5	95	90	95	95	85	3
0.002 N sulfuric acid	30	91	88	98	44	25	4
0.52 N acetic acid...	30	60	16	8	3	3	1
		Relative Availability to Plants (9)*					
Pot experiments....	—	88	—	25	—	9	8
Neubauer experiments..........	—	79	—	18	—	10	7

*Calcium monophosphate taken to be 100. Soils with pH below 6.0.

The different kinds of phosphates are classified according to their solubility as follows:

1. Pure calcium phosphates, completely soluble in all extractants used.
2. Iron and aluminum phosphates, practically insoluble in all extractants.
3. Phosphates similar to rock phosphate completely soluble in 0.2 N nitric acid and 0.75 N hydrochloric acid, almost completely soluble in 0.002 N sulfuric acid, but only slightly soluble in 0.52 N acetic acid.
4. Phosphates similar to fluorapatite completely soluble in 0.2 N nitric acid after 30 minutes and in 0.75 N hydrochloric acid after 5 minutes, but only partially soluble in these extractants with shorter periods of extraction, slightly soluble in 0.002 N sulfuric acid after 30 minutes, and very slightly soluble in acetic acid.
5. Phosphoric acid adsorbed by aluminosilicate clay minerals, such as bentonite and kaolinite. Burd and Murphy (2) state that phosphate is not displaced from the adsorbed condition by hydrochloric acid of any pH short of one which breaks down the aluminosilicates of the adsorbing complex. Such adsorbed phosphate may be released by citric acid or sodium hydroxide (2) or by ammonium fluoride (1).

The quantities of phosphoric acid in the form of calcium phosphate in a soil should seldom be larger than the quantity dissolved by the acetic acid extractant. The quantity of phosphoric acid in fluophosphates similar to rock phosphate and fluorapatite should seldom exceed the difference between that dissolved by the stronger solvents and that dissolved by the acetic acid. The difference in the quantities of phosphoric acid dissolved by these two solvents can be considered to be due chiefly to calcium fluophosphates.

EFFECT OF EXTRACTANT ON FIXATION OF PHOSPHORIC ACID

The quantity of phosphoric acid in a soil extract is the net resultant of the solution of soil phosphates and the fixation of phosphoric acid from solution by other compounds in the soil (4). Differences in the phosphoric acid found in different extracts may be partly due to differences in the effect of different extractants upon fixation of the dissolved phosphoric acid. In order to test this point, six soils of high capacity to fix phosphoric acid were extracted with the different extractants to which had been added sodium phosphate carrying phosphoric acid equivalent to 100 p.p.m. of soil. After extraction, the amount of phosphoric acid not fixed from the additional phosphate was estimated by subtracting from the phosphoric acid found in the extract the amount of phosphoric acid soluble in the soil without the addition of phosphate. The results secured, given in Table 3, show that fixation from 0.52 N acetic acid was the same as from water, that fixation from 0.2 N nitric acid was the same as from water on three soils but considerably lower on three other soils, and that fixation from 0.75 N hydrochloric acid was much lower than from water. The differences in fixation would account for only a small part of the difference in the phosphoric acid dissolved from soils by

the acetic acid and by the other solvents. Fixation from acetic acid was usually greater than from the other acids.

TABLE 3.—*Effect of different extractants upon fixation of phosphoric acid by soils.*

Soil type	Percentage of phosphoric acid fixed from			
	Water	0.2 N nitric acid	0.75 N hydrochloric acid	0.52 N acetic acid
Wilson clay loam	54	59	11	64
Crockett fine sandy loam	61	40	18	59
Nacogdoches fine sandy loam	70	71	25	74
Kirvin fine sandy loam	73	70	26	76
Lade Charles clay	91	64	17	89
Gainer clay	96	78	33	96
In Presence of Ferric Iron in Solution				
Nueces fine sand	10	0	—	2
Refugio loamy fine sand	10	5	—	5
Bowie fine sandy loam	11	4	—	5
Miles fine sandy loam	12	7	—	4
Edna fine sandy loam	19	11	—	7
Ruston fine sandy loam	26	1	—	8

Peech and English (10) state that one of the objectionable features of the mineral acid extractants is the unduly large amounts of dissolved iron and aluminum which may cause partial precipitation of the dissolved phosphoric acid. The effect of soluble iron on phosphate fixation was studied on six soils of low fixing capacity by adding to the extractant ferric chloride solution carrying 0.002 gram of ferric oxide. On these soils, fixation from both nitric acid and acetic acid was less than from water. The additional iron was without effect (Table 3). The filtrates from both extractions were allowed to stand a week, with no evidence of any precipitation of iron phosphate. The soils listed in Table 3 were all low in capacity to neutralize acid. Appreciable amounts of free acid still remained in all extracts at the end of the extraction. Some soils are so high in neutralizing capacity, or basicity, that little or no free acid remains in the extract.

An experiment was made in which calcium carbonate equivalent to one and one-half times the acid was added to 100 cc of 0.2 N nitric acid containing 1 milligram of phosphoric acid in sodium phosphate. The mixture was stirred for 30 minutes and 95% of the phosphoric acid was precipitated. The remaining 5% was precipitated after standing overnight. Calcium, iron, and aluminum phosphates are known to be quite insoluble at or slightly above the neutral point (12). When too much of the acid in the solvent is neutralized by the soil, phosphates otherwise in solution may be precipitated.

RELATION OF SOLUBILITY OF PHOSPHATES TO AVAILABILITY TO PLANTS

Four of the phosphates used in this study had been used in cooperative experiments of the Association of Official Agricultural Chemists

(11) to determine their availability to plants on different soils. The average relative availabilities of the phosphoric acid, as compared with calcium monophosphate as 100, are shown in Table 2 (omitting tests by one collaborator which are out of line with the others).

The solubilities of calcined phosphate in nitric, hydrochloric, and sulfuric acid are in good agreement with the availability of this material to plants. The solubility of the phosphoric acid in Tennessee rock phosphate and fluophosphate in all solvents except acetic acid was much higher than their availability to plants. The solubility in acetic acid was lower than the availability. The availability of the natural iron and aluminum phosphate was higher than its solubility in any of the extractants. This difference is probably due to slow hydrolysis of the phosphate in the soil over the longer experimental periods used for the plants. The solubility of all four of these phosphates was much lower in the acetic acid than their availability to plants. The acetic acid failed to dissolve a considerable amount of phosphoric acid which would be available to plants.

"Colloidal" phosphate and rock phosphate B were more soluble in nitric, hydrochloric, and sulfuric acids than they were available to plants in pot experiments conducted by the authors.

Hydrated and anhydrous calcium phosphate, calcium hydroxy-phosphate, fused rock phosphate, and basic slag, which were almost completely soluble in all extractants, were practically as available as water-soluble calcium monophosphate (12).

Chemical solvents may distinguish between phosphates which have a high availability to plants and those which have a low availability, but they do not measure exactly the availability of the phosphoric acid in these minerals. The availability of the same phosphate to plants depends upon the kind of plant, the soil, and the conditions under which the test is made, so that results secured with the same phosphates in different tests may differ considerably (11).

RELATIVE AMOUNTS OF PHOSPHORIC ACID EXTRACTED FROM SOILS BY DIFFERENT SOLVENTS

Soluble phosphoric acid in 34 surface soils of low basicity (equivalent to less than 2% calcium carbonate) was determined by the several methods, as shown in Table 4. Also shown in Table 4 are the weights of one crop of corn grown in pot experiments with and without the addition of phosphoric acid, and the amount of phosphoric acid in the corn crop from the unphosphated soil. The soils are arranged in the order of the quantity of phosphoric acid in the corn crop. From most of the soils, the 0.2 N nitric acid, the 0.75 N hydrochloric acid, and the 0.002 N sulfuric acid dissolved practically the same quantities of phosphoric acid. The exceptions are so few that separate discussion of these solvents is not necessary. The soils are also divided into three groups according to the phosphoric acid removed by the corn. The phosphoric acid dissolved by the solvent, on an average, increased with the phosphoric acid removed by the corn. The differences among soils are less striking with the acetic acid than with the other solvents.

The acetic acid dissolves much less phosphoric acid than the other solvents (60% to 80% for the averages for the three groups). Assuming that this solvent dissolved the calcium phosphate, while the other solvents dissolved the calcium phosphate and also calcium fluorophosphates, the three groups would average not more than 4, 9, and 16 p.p.m., respectively, of phosphoric acid in calcium phosphate and 7, 13, and 63 p.p.m. in calcium fluorophosphate. Small amounts of the soluble phosphoric acid are probably derived from the iron and aluminum phosphates, but these phosphates are only slightly soluble. In soils of high fixing power, some of the dissolved phosphoric acid is removed from solution by fixation.

Comparison of the quantities of phosphoric acid dissolved by the weak solvents with those of total phosphoric acid shows that the major part of the phosphorus in these soils is in the form of iron, aluminum, and organic and adsorbed phosphates.

Coefficients of correlation (r) for the relation between the quantity of phosphoric acid dissolved from the 34 soils by the different methods and the quantity of phosphoric acid removed from the soils in one crop of corn were as follows:

	r	r^2
0.002 N sulfuric acid................	.838	.70
0.2 N nitric acid (colorimetric).......	.819	.67
0.2 N nitric acid (regular volumetric)	.797	.64
0.75 N hydrochloric acid (1 min.).....	.699	.49
0.52 N acetic acid-sodium acetate....	.580	.34

The coefficients of correlation (r) are all highly significant, but that for the acetic acid extractant is significantly lower than for any other extractant. The proportion of variation in quantities of phosphoric acid removed by the corn which can be attributed to concurrent variations in soluble phosphoric acid was estimated by squaring the coefficients of correlation (r^2). This proportion amounted to about two-thirds for sulfuric acid and nitric acid extractants, about one-half for hydrochloric acid, and about one-third for acetic acid. The inclusion of phosphoric acid which was soluble in nitric or sulfuric acids but insoluble in acetic acid thus doubled the relation between the phosphoric acid dissolved by the solvent and that removed from these soils by the corn crop. This indicates that an extractant for phosphoric acid in soils should be such that it includes some estimation of phosphoric acid obtainable by the plant from phosphates similar in character to rock phosphate and fluorapatite.

DISCUSSION

Calcium, iron, aluminum phosphates, adsorbed phosphates, and organic compounds of phosphorus comprise most of the phosphates found in soils. Some may be within soil particles or schists or other minerals and so unavailable to plant roots. These phosphates, when pure, are soluble in 0.2 N nitric acid (4) and are highly available to plants (8, 11). In soils, however, most calcium phosphates are not pure, but similar in character to rock phosphate or apatite, and iron

TABLE 4.—*Phosphoric acid in various soils soluble in different extractants.*

Soil type	Total P_2O_5 in soil, %	Weight of corn, grams		P_2O_5 in corn, p.p.m. of soil	Soluble phosphoric acid, p.p.m.					
					0.2 N nitric		0.75 N hydrochloric acid		0.002N sulfuric acid	0 0.52 N acetic acid
		NK	NPK		Regular volumetric	Colormetric	1 min.	5 min.		
				Group A						
Gainer clay	0.028	3.4	—	1.4	5	6	10	—	8	1
Ruston fine sandy loam	0.019	3.7	48.5	1.5	7	5	5	—	5	2
Duval fine sandy loam	0.085	4.9	37.3	1.9	12	5	8	—	8	2
Crockett fine sandy loam	0.038	3.3	—	1.9	19	18	16	—	14	4
Victoria clay	0.023	6.3	55.3	2.2	13	10	11	—	7	2
Nacogdoches fine sandy loam	0.061	7.8	35.2	3.3	6	3	10	—	3	2
Webb fine sandy loam	0.029	8.8	26.0	3.6	16	11	9	—	22	6
Nueces fine sand	0.024	7.6	—	3.8	16	16	9	—	15	5
Miles fine sandy loam	0.018	10.6	—	4.1	8	16	14	—	16	5
Bowie fine sandy loam	0.021	8.8	35.3	4.3	12	8	10	—	15	1
Refugio loamy fine sand	0.015	14.0	46.6	4.7	6	12	9	—	15	5
Quincy loamy fine sand	0.028	11.4	43.5	4.7	25	23	17	—	21	13

Group B										
Kirvin fine sandy loam	0.034	12.9	—	5.6	12	10	10	—	11	3
Edna fine sandy loam	0.015	18.2	—	6.6	18	19	16	—	18	10
Amarillo fine sand	0.014	14.0	27.0	6.6	23	12	11	—	14	7
Bowie fine sandy loam	0.027	10.2	—	6.7	42	39	44	—	48	21
Lade Charles clay	0.034	13.6	—	6.7	13	19	27	—	19	6
Hockley fine sandy loam	0.017	14.9	51.1	6.9	24	24	21	—	28	16
Wilson fine sandy loam	0.025	18.6	32.5	7.3	19	29	25	—	26	10
Wilson very fine sandy loam	0.047	15.4	29.5	9.7	28	24	20	—	25	6
Wilson clay loam	0.036	14.2	38.1	9.9	20	18	26	—	47	5
Group C										
Wilson clay loam	0.038	18.0	37.8	10.7	49	39	31	42	42	6
Wilson clay loam	0.025	21.4	49.8	10.9	5	28	20	—	23	6
Kirkland very fine sandy loam	0.048	30.1	43.9	11.8	77	85	54	76	45	12
Calumet very fine sandy loam	0.045	30.6	39.0	12.7	63	52	45	52	39	10
Wilson very fine sandy loam	0.032	23.9	37.3	13.6	49	53	20	49	51	24
Tillman clay loam	0.065	38.0	56.1	13.7	128	131	101	143	84	6
Victoria fine sandy loam	0.145	29.7	30.8	14.0	91	97	79	84	91	41
Kirkland clay loam	0.059	25.4	29.7	14.6	67	84	73	88	58	8
Victoria fine sandy loam	0.060	20.1	24.8	14.8	136	138	115	132	110	37
Vernon very fine sandy loam	0.043	30.7	48.1	15.5	45	41	45	—	38	14
Wilson clay loam	0.043	30.3	37.8	18.8	59	57	43	49	53	14
Orelia clay loam	0.070	22.6	25.5	19.2	83	88	34	88	87	14
Miles fine sandy loam	0.054	41.2	44.4	19.7	128	129	98	118	87	18
Average group A (12)	0.032	—	—	3.1	12	11	11	—	12	4
Average group B (9)	0.028	—	—	7.3	22	22	22	—	26	9
Average group C (13)	0.056	—	—	14.6	75	79	58	—	62	16

and aluminum phosphates are usually hydrated compounds of low solubility and availability to plants. While vivianite (hydrated ferrous phosphate) is soluble in 0.2 N nitric acid (4) and 0.002 N sulfuric acid (14), it is not likely to be present in well-aerated soils. Most of the iron phosphates in surface soils are probably similar to dufrenite, hydrated ferric phosphate (14), which is nearly insoluble in acid extractants (4, 12) and largely unavailable to plants (8). Since these natural iron and aluminum phosphates are only slightly soluble in any of the extractants used, the difference in results secured with the acetic acid, as compared with the other extractants, is largely due to differences in their capacity to dissolve phosphoric acid from soil compounds similar to rock phosphate and apatite.

None of the extractants give quantitative estimates of the quantity of phosphoric acid which is or may become available to plants. There may be a significant relation between the quantity dissolved by the extractants and the quantity taken up by plants, but this relation has to be determined for any particular group of soils by plant experiments. The relation may or may not be significant, and the degree of relation may vary widely with different groups of soils (6). Dilute acids do not remove all of the phosphoric acid which is readily taken up by plants. Plants may secure their phosphoric acid either directly or indirectly from soil materials insoluble in any of the extractants. Seventy Texas soils, which averaged 28 p.p.m. phosphoric acid soluble in 0.2 N nitric acid before growing crops in pot experiments, supplied an average of 23 p.p.m. to the plants and contained an average of 31 p.p.m. after cropping (6). Extraction procedures which include in their estimate more of the soil compounds which may provide phosphoric acid to plants and which give results which show a significantly higher relation between solubility and availability to plants are obviously to be preferred to those procedures which do not do so.

Solubility of the soil phosphates is only one of several factors which affect the capacity of the soils to supply phosphoric acid to plants (6). This capacity is only one of many factors which determine the performance of a crop in the field or the response of a crop to phosphatic fertilization.

It is unfortunate that any chemical method should be claimed to measure the available phosphoric acid in soils. The most that the chemical method can do is to ascertain the quantity of phosphoric acid dissolved by the solvent used. From the chemical data, and from other data secured in appropriate and sufficient experimentation, certain conclusions may be drawn as to the ability of the soils to supply phosphoric acid to plants, but any claim that a chemical method measures the availability of phosphates in the soil is not supported by the facts.

SUMMARY

The solubility of several phosphates and of 34 soils of low basicity in 0.2 N nitric acid, 0.75 N hydrochloric acid, 0.002 N sulfuric acid, and 0.52 N acetic acid in 10% sodium acetate was determined.

Pure calcium phosphates were completely soluble in all extractants. Rock phosphates were almost completely soluble in 0.75 N hydrochloric acid and 0.2 N nitric acid, less soluble in 0.002 N sulfuric acid, and practically insoluble in 0.52 N acetic acid. Apatite was not completely soluble in the different extractants; the solubility was influenced by the strength of the acid and the period of extraction. The differences between acetic acid and the other solvents were probably due to the presence of calcium fluophosphates.

The quantity of phosphoric acid dissolved from the soils by 0.52 N acetic acid was from 20% to 40% of that dissolved by the mineral acid extractants.

Fixation of dissolved phosphoric acid from the acetic acid was about the same as from water, but was less from the other solvents.

The amount of phosphoric acid removed by corn from 34 soils was related to the phosphoric acid dissolved by the solvent. The correlation coefficients for the relation between the phosphoric acid removed by the crops and the phosphoric acid dissolved by the solvents were much larger for the mineral acids. Chemical methods determine the easily soluble phosphates but do not determine the availability of the soil phosphates. Any interpretation of the chemical data secured in terms of availability should be aided by agronomic data.

LITERATURE CITED

1. BRAY, ROGER H., and KURTZ, L. T. Determination of total, organic, and available forms of phosphorus in soils. Soil Sci., 59:39–45. 1945.
2. BURD, JOHN S., and MURPHY, J. F. The use of chemical data in the prognosis of phosphate deficiency in soils. Hilgardia, 12:323–340. 1939.
3. DENIGES, G. Reaction de coloration extremenent sensible des phosphates et des arseniates. Compt. Rend. Acad. Sci. (Paris), 171:802–804. 1920.
4. FRAPS, G. S. Active phosphoric acid and its relation to the needs of soils for phosphoric acid in pot experiments. Texas Agr. Exp. Sta. Bul. 126. 1909.
5. ————, and FUDGE, J. F. Rapid chemical methods for the estimation of the capacity of the soil to supply phosphoric acid to plants. Jour. Amer. Soc. Agron., 25:217–230. 1933.
6. ————, ————. Some factors affecting the utilization of phosphoric acid in soils by plants in pot experiments. Texas Agr. Exp. Sta. Bul. 647. 1944.
7. PARKER, F. W., and FUDGE, J. F. Soil phosphorus studies. I. The colorimetric determination of organic and inorganic phosphorus in soil extracts and the soil solution. Soil Sci., 24:109–117. 1927.
8. MARAIS, J. S. The comparative agricultural value of insoluble phosphates of aluminum, iron, and calcium. Soil Sci., 13:255–409. 1922.
9. MORGAN, M. F. Chemical soil diagnosis by the universal soil testing system. Conn. Agr. Exp. Sta. Bul. 450. 1941.
10. PEECH, MICHAEL, and ENGLISH, LEAH. Rapid microchemical tests. Soil Sci., 57:167–195. 1944.
11. ROSS, W. H., JACOBS, K. D., and BEESON, K. C. Report on phosphoric acid. Composition and fertilizer efficiency of the insoluble phosphates in ammoniated superphosphates. Jour. A.O.A.C., 15:227–226. 1932.
12. STELLY, M., and PIERRE, W. H. Forms of inorganic phosphorus in the C horizon of some Iowa soils. Soil Sci. Soc. Amer. Proc., 7:139–147. 1943.
13. THORNTON, S. F., CONNER, S. D. and FRASER, R. R. The use of rapid chemical tests on soils and plants as aids in determining fertilizer needs. Ind. Agr. Exp. Sta. Circ. 304. 1934.
14. TRUOG, E. The determination of readily available phosphorus in soils. Jour. Amer. Soc. Agron., 22:874–882. 1930.

DETERIORATION OF CLIPPED CAGED AREAS IN PERMANENT PASTURES[1]

B. A. Brown and R. I. Munsell[2]

FOR many obvious reasons, mechanical methods have been substituted for grazing animals in numerous experiments designed to measure the production of pastures. In spite of the recognized facts that animals, by selective grazing, may cause important botanical differences between grazed and mechanically harvested areas (9)[3] and that different kinds of vegetation do not affect animals alike (8), the results from mowed plots are now generally accepted as being closely correlated with those obtained by actual grazing. Considerable evidence in substantiation of this view has been published (1, 4, 6, 8).

The purpose of this paper is to summarize the botanical and chemical characteristics and the yields of the herbage clipped from caged areas in three differently fertilized, quantitatively grazed permanent pasture plots of the long-time grazing experiment at Storrs.

EXPERIMENTAL

Two series of eight cages each were distributed in each of three differently fertilized grazed plots. The first series of cages was placed in 1931 and was kept on the *same spots* until 1942, when this phase of the experiment was terminated. These will be designated as the *fixed* cages. The second series was placed on the pastures in 1932 and these cages were changed to different locations every spring, except 1942, before grazing began. They will be called the *moved* cages. A site which appeared representative of the local section of a plot was chosen for each cage. A *fixed* and a *moved* cage were placed within 30 feet of each other.

The cages were 3 feet square and 1 foot high. They were made of soft wood frames covered with ordinary poultry wire fencing, 1-inch mesh on the sides, 2-inch mesh on the tops. The cages were wired to stakes driven in the ground to prevent them from being moved by the heifers which grazed the pastures.

The pastures were grazed rotationally, a grazing period starting whenever the grasses were 4 to 5 inches high. Stocking was such that the pasturage was consumed in about two weeks. Before each period ended, the vegetation in the cages was cut 1 inch above the soil with grass shears. The crop from each cage was placed in a paper bag, air-dried at room temperatures, and finally oven-dried to obtain yields of dry matter. The average number of cuttings per season for the differently fertilized plots were no treatment, 3.8; LPK, 4.3; LPKN, 4.8.

In 6 of the 10 years, the herbage from one cutting of the eight replicate cages of a series was composited after oven-drying, sub-sampled, and analyzed for some of the common feed and fertilizer constituents.

The areas occupied by grasses, weeds, and bare ground in each cage were estimated several times during the 10-year period. On plots receiving superphosphate, the predominating grasses were Kentucky bluegrass, *Poa pratensis* L., and Rhode Island bent grass, *Agrostis tenuis* Sibth. Without superphosphate, there was little bluegrass, but much poverty grass, Danthonia spicata (L.) Beauv.

The caged areas were fertilized the same as the plots in which they were located. Because of the numerous rocks on these pastures, fertilizers were applied by hand, the amount for each 1/20 acre being weighed separately and spread carefully on each section. The cages were on plots treated as follows:

Plot 5, no fertilizer.

Plot 8N, limestone, superphosphate and muriate of potash. The limestone was

[1]Contribution from the Department of Agronomy, Storrs (Connecticut) Agricultural Experiment Station. Received for publication February 23, 1945.

[2]Associate Agronomist and Assistant Agronomist, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 547.

added at 1 ton in 1924 and in 1929, the superphosphate in amounts to provide P_2O_5 at 80 pounds, and the potash to furnish K_2O at 50 pounds in 1924, 1929, 1932, 1935, and 1938.

Plot 6N, the same minerals as 8N plus N at 56 pounds in April each year from 1929 to 1941.

RESULTS

BOTANICAL

Only a few seasons had passed before it was evident that a vegetative deterioration had occurred in the *fixed* cages. The turf was thinner and weeds were more plentiful than in the *moved* cages. This statement is supported by the data in Table 1, which gives the percentages of grass and weeds in the two fertilized pastures, with cages, in 1932, 1934, and 1941. (Similar data are not available for the unfertilized plot.) These data indicate a progressive decline in the turf.

TABLE 1.—*Comparison of grasses and weeds in "fixed" and "moved" cages on fertilized plots.**

Plot No.	Fertilization	Percentage of area occupied by†					
		Grasses			Weeds		
		1932	1934	1941	1932	1934	1941
		Fixed Cages					
8N	LPK	71	59	44	17	22	44
6N	LPKN	84	60	58	6	15	36
		Moved Cages					
8N	LPK	78	76	80	8	—	12
6N	LPKN	82	74	85	7	5	10

*Similar data are not available for the unfertilized plot.

†Values are averages of eight cages.

A summary of the final readings made in June 1942 after the *fixed* cages had been on the same spot for 11 years and the *moved* cages for 1 year are presented in Table 2. That summary illustrates the marked depreciation of the continuously clipped areas. It shows, also, that the two plots fertilized with LPK or LPKN did not differ greatly either in the amounts of grasses, weeds, and bare ground or in the degree of deterioration in the *fixed* cages. Both had about two-thirds as much grass and over twice as many weeds in the *fixed* as in the *moved* cages.

In the unfertilized plot, the vegetation in both sets of cages varied appreciably from similarly managed sets in the fertilized pastures. There was much less grass but a much smaller difference between the *fixed* and *moved* cages. In marked contrast to the grasses, the *fixed* cages in the unfertilized plot had fewer weeds than either the *moved* cages in the same plot or the *fixed* cages in the fertilized plots. The reasons for these unexpected variations are not known, but it seems probable the continuous clipping killed some of the numerous

weeds and on this phosphorus-deficient soil grasses did not spread into the vacated space.

TABLE 2.—*Final differences between "fixed" and "moved" caged areas.*

Plot No.	Fertilization	Percentage area of occupied in June 1942 by*					
		Grasses		Weeds		Bare ground	
		Fixed	Moved	Fixed	Moved	Fixed	Moved
5	None	49	58	15	24	29	11
8N	LPK	47	71	38	17	8	3
6N	LPKN	51	76	33	12	9	3

*Values are averages of eight cages.

The amount of bare ground was 29% of the area in the unfertilized *fixed* cages and that value is approximately three times that for the unfertilized *moved* cages and the fertilized *fixed* cages. In fact, bare ground was so prevalent in some of the *fixed* cages of the unfertilized plot that some erosion had occurred, something not at all evident on the grazed areas.

The general situation in respect to the deterioration of the caged areas clipped for 11 years might be summarized by repeating a notation made in 1941 to the effect that, "The areas in the fixed cages have many more weeds and thinner turf than any spots in their vicinity or even in the entire plot".

CHEMICAL ANALYSES

A summary of the chemical analyses may be found in Table 3. In spite of the great botanical differences between the *fixed* and *moved* cages, the chemical analyses, excepting for K, do not differ much between the two sets of cages in any of the plots. This is probably due to the immature stage at which all vegetation was cut.

TABLE 3.—*Chemical analyses of clippings from "fixed" and "moved" cages.*

Plot No.	Fertilization	Percentage of dry matter*									
		Protein		Fiber		P		Ca		K	
		Fixed	Moved	Fixed	Moved	Fixed	Moved	Fixed	Moved	Fixed	Moved
5	None	13.9	13.7	25.1	24.7	0.19	0.19	0.69	0.68	1.49	1.71
8N	LPK	17.3	17.0	21.8	23.1	0.36	0.34	0.82	0.77	2.75	2.32
6N	LPKN	19.1	18.9	22.3	23.3	0.34	0.33	0.74	0.66	2.47	2.42

*Values are averages of six years (1932–36 plus 1938) for protein, P, and Ca, and averages of three years (1935, 1936, and 1938) for fiber and K. Superphosphate and muriate of potash were applied in 1932, 1935, and 1938.

In the unfertilized and LPK plots, the values for K do differ markedly but in opposite directions. In the unfertilized plot, the vegetation under the *moved* cages contained much more K than the *fixed* cages, while the reverse was true of the LPK herbage. These results appear to be connected with the prevalence of weeds, *viz.*, the more weeds in the cage of a given plot, the more K in the dry matter of the clippings. In all cases, however, the fertilized herbage contained more K than the unfertilized.

YIELDS

The yields of digestible nutrients as measured by grazing were calculated by using feeding standards for growing heifers (2, 3). The dry matter from the clippings of both the *fixed* and *moved* cages was estimated to be 72% digestible, as suggested by the several pasture committees (7). The annual yields of total digestible nutrients from all three methods, the yields of the *moved* cages as percentages of those of the *fixed* cages, and the grazed yields as percentages of those from the *fixed* and *moved* cages have been brought together in Table 4.

The outstanding features of the data in Table 4 are the consistently smaller yields of the *fixed* cages as compared to the *moved* ones of the same plot, the close relationships ($r = 0.95 \pm 0.009$ and 0.93 ± 0.013 respectively) between yields as determined by grazing and those determined by clipping either the *fixed* or the *moved* caged areas, and the increasing differences in favor of the *moved* cages with decreasing fertilization. As far as total yields, including weeds, are concerned, there appears to have been no trend toward greater divergencies between the *fixed* and *moved* cages with the progress of time.

DISCUSSION

In comparison with the grazed parts of three variously fertilized permanent pastures, caged areas, clipped with grass shears for 11 years, showed very definite signs of deterioration. This was evidenced by much less grass, many more weeds, and consistently smaller yields of dry matter, including weeds. The causes for these results have not been determined, but a few possible reasons are mentioned as follows:

1. The clipping removed all the vegetation at once, while probably this did not occur in grazing. The clipping also may have been somewhat closer to the ground than the grazing. An argument against this suggestion is that in other experiments here, lawnmowing the same grasses when 3 inches to either ½ or 1 inch above ground has not had such unfavorable effects, even when all clippings were removed for several years.

2. The increasing differences between the yields of the *fixed* and *moved* cages with decreasing adequacy of the added fertilizers indicates some benefit from the voidings of the animals to the unprotected area. However, this would not explain the marked changes in grass and weed populations.

3. One or more elements unfavorable to the grasses may have been dissolved from the poultry wire used to cover the cages. This

TABLE 4.—*Total digestible nutrients from three systems of measurements.*

	Total pounds per acre										
	1932	1933	1934	1935	1936	1937	1938	1939	1940	1941	Average, 10 years
Plot 5, No Fertilizer											
As measured by grazing*	531	526	674	484	613	590	631	601	529	499	568
From clipped fixed cages†	369	418	831	346	573	478	438	526	587	428	499
From clipped moved cages‡	570	813	1,303	557	1,016	662	683	771	897	719	799
Yields of moved cages as % of fixed cages	154	194	157	161	177	138	156	147	153	168	161
Grazed yields as % of fixed cages	144	126	81	140	107	123	144	114	90	117	119
Grazed yields as % of moved cages	93	65	52	87	60	89	92	78	59	69	74
Plot 8N, LPK											
As measured by grazing*	1,159	1,251	1,164	1,159	1,193	1,380	1,633	1,191	1,144	1,286	1,256
From clipped fixed cages†	1,529	1,874	1,726	1,493	1,315	1,851	1,894	1,567	1,668	1,499	1,642
From clipped moved cages‡	1,773	2,371	2,506	1,807	1,922	2,348	2,582	1,907	2,254	2,317	2,179
Yields of moved cages as % of fixed cages	116	127	145	121	146	127	136	122	135	155	133
Grazed yields as % of fixed cages	76	67	67	78	91	75	86	76	69	86	77
Grazed yields as % of moved cages	65	53	46	64	62	59	63	62	51	56	58
Plot 6N, LPKN											
As measured by grazing*	1,356	1,784	1,910	1,511	1,711	1,731	1,686	1,852	1,742	1,556	1,684
From clipped fixed cages†	1,927	2,226	2,321	2,006	1,791	1,773	2,732	2,105	1,894	2,040	2,082
From clipped moved cages‡	1,976	2,538	3,221	1,956	2,179	2,330	2,982	2,654	2,169	2,157	2,416
Yields of moved cages as % of fixed cages	103	114	139	98	122	131	109	126	115	106	116
Grazed yields as % of fixed cages	70	80	82	75	96	98	62	88	92	76	82
Grazed yields as % of moved cages	69	70	59	77	79	74	57	70	80	72	71

*Grazed with yearling dairy heifers. The yields of TDN calculated from the weights maintained and gained on each pasture, using the feeding standards published by Eckles, and Gullickson (2) and Gullickson and Eckles (3).

†Average yields from eight cages kept on the same areas from 1931 to 1942. Dry matter was estimated to be 72% digestible.

‡Average yields from eight cages moved to a different location before grazing started each spring. Dry matter was estimated to be 72% digestible.

was suggested by the observation that under a temporary poultry fence, which occupied the site for only part of one season, thrifty bluegrass died and was replaced by weeds. The fact that the grasses outside of the *fixed* cages and immediately contiguous to the wire were very thrifty, appears to eliminate this point.

4. Perhaps the most commonly suggested factor is that grazing animals prefer some species to others and consequently may overgraze or undergraze contiguous spots. This does not seem to apply to the *fertilized* plots in this experiment because weeds were much more prevalent in the continuously mowed *fixed* cages where there was no selection. On the other hand, there were more weeds on the grazed than on the mowed parts of the unfertilized plot, a result possibly due to their refusal by the animals, which, in this case, had access to relatively poor pasturage and consequently may have selected only the best.

5. Compaction of soil by animals has also been suggested as a cause of differences between grazed and mowed areas. In this experiment, the unfertilized pasture was exposed to the treading of much fewer animals than the fertilized plots. Since the physical properties of the soil from the *fixed* and *moved* cages were not studied, the authors have no data on which to base an opinion as to the importance of this factor.

SUMMARY

In each of three differently fertilized, grazed permanent pastures, caged areas, clipped with grass shears for 11 years, had decidedly less grass, many more weeds, much more bare ground, and consistently smaller yields, including the weeds, than nearby areas caged for only 1 year. Except for K, there were no important differences between the chemical analyses of the vegetation from the *fixed* and *moved* cages.

The 10-year average difference in total yields between continuously caged, clipped areas and those caged and clipped for only one season was greatest (61%) on the unfertilized pasture, medium (33%) under LPK fertilization, and least (16%) where, in addition to LPK, a liberal amount of N was applied annually in April.

For the differently fertilized pastures, the average grazed yields varied drom 71 to 119% of the yields from the *fixed* cages and from 58 to 74% of the yields from the *moved* cages. Although the yields of the *fixed* cages were closer to the grazed yields than those from the *moved* cages, the markedly greater prevalence of weeds under continuous clipping throws much doubt on the applicability of that method as a substitute for grazing in measuring the production of pastures.

LITERATURE CITED

1. Brown, B. A. Technic in pasture research. Jour. Amer. Soc. Agron., 29:468–476. 1937.
2. Eckles, C. H., and Gullickson, T. W. Nutrient requirements for normal growth of dairy cattle. Jour. Agr. Res., 42:603–616. 1931.
3. Gullickson, T. W., and Eckles, C. H. Nutrients used for maintenance by growing dairy cattle. Jour. Agr. Res., 42:593–601. 1931.

4. HODGSON, R. E., KNOTT, J. C., MILLER, V. L., and WOLBERG, F. B. Measuring the yield of nutrients of experimental pastures. Wash. Agr. Exp. Sta. Bul. 411. 1942.
5. MCLEAN, EUGENE O., SMITH, G. E., and ALBRECHT, WM. A. Biological assays of some soil types under treatments. Soil Sci. Soc. Amer. Proc., 8:282–286. 1944.
6. NOLL, CHARLES F., BECHDEL, S. I., WILLIAMS, P. S., SKAGGS, S. R., and HEIN, M. A. Pasture fertilization. Pa. Agr. Exp. Sta. Bul. 460. 1944.
7. Preliminary report of pasture investigations technique. Joint Committee of American Society of Agronomy, American Dairy Science Association, and American Society of Animal Production. Mimeographed. 1942.
8. ROBINSON, R. R., PIERRE, W. H., and ACKERSON, R. A. A comparison of grazing and clipping for determining the response of permanent pastures to fertilization. Jour. Amer. Soc. Agron., 29:349–359. 1937.
9. STAPLEDON, R. G., and JONES, MARTIN G. The sheep as a grazing animal and as an instrument for estimating the productivity of pastures. Welsh Plant Breeding Sta. Bul., Series H, No. 5. 1927.

INFLUENCE OF SPACING ON YIELD AND OTHER CHARACTERS IN SOYBEANS[1]

A. H. PROBST[2]

MANY varieties and strains of soybeans differing in numerous characters frequently are tested together in rod-row nursery yield trials. Although much care may be taken to obtain comparable stands, there may be considerable variation in stand among different strains, or even within strains in different replications. Published data on the influence of plant spacing on different varieties of soybeans in nursery trials are very limited.

To study the effects of plant spacing of soybeans on yield and several other characters commonly obtained in the evaluation of varieties, an experiment on spacing was carried out with four varieties of soybeans at Lafayette, Ind., by the U. S. Regional Soybean Laboratory[3] and the Purdue University Agricultural Experiment Station, cooperating.[4] The work was conducted over the 4-year period from 1938 to 1941, inclusive.

Wiggans[5] found that the soybean plant has the ability to make wide adjustments to space and that optimum rates and spacings for soybeans should be determined not only for the various soybean-producing areas but also for the varieties to be grown.

MATERIAL AND METHODS

The Mukden, Mandell, Dunfield, and Illini soybean varieties were used in this experiment. Mukden averaged 5 days earlier in this experiment than the other varieties which are of approximately the same maturity. All varieties are well adapted at Lafayette, Ind. Illini lodges the most and Mukden the least at the usually recommended rates of seeding.

A split-plot Latin square design was used with four replications of each variety. Varieties were on the main plots, while the sub-plots were devoted to spacing. Excessive amounts of seed were planted in single-row plots 18 feet long with 30 inches between rows. After emergence, the plants were thinned to 1, 2, 3, 4, and 5 inches apart in the various rows. The rows were trimmed to 16 feet in length at harvest and the yield of individual replications obtained from an area 2½ by 16 feet.

Lodging was recorded on a scale of 1 to 5 taken visually on each plot at maturity according to the following criteria: 1, almost all plants erect; 2, either all plants leaning slightly, or a few plants down; 3, either all plants leaning moderately,

---

[1]Contribution from the Division of Forage Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. Regional Soybean Laboratory, U. S. Dept. of Agriculture, and Purdue University Agricultural Experiment Station, Lafayette, Ind., cooperating. Received for publication February 28, 1945.

[2]Associate Agronomist.

[3]A cooperative organization participated in by the Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, of the U. S. Department of Agriculture, and the Agricultural Experiment Stations of Alabama, Arkansas, Florida, Georgia, Illinois, Indiana, Iowa, Kansas, Louisiana, Michigan, Minnesota, Mississippi, Missouri, Nebraska, North Carolina, North Dakota, Ohio, Oklahoma, South Carolina, South Dakota, Tennessee, Texas, Virginia, and Wisconsin.

[4]Journal paper No. 184, Purdue University Agricultural Experiment Station.

[5]WIGGANS, R. G. The influence of space and arrangement on the production of soybean plants. Jour. Amer. Soc. Agron., 31:314–321. 1939.

or 25% to 50% of the plants down; 4, either all plants leaning considerably, or 50% to 80% of the plants down; 5, all plants down badly.

Height was determined as the average length of plants in a plot from the ground to the top extremity at the time of maturity.

The number of days to mature was recorded as the number of days from planting until the plants were sufficiently mature to combine satisfactorily.

Seed size was determined by weighing 1,000 seeds from each plot of each variety and spacing.

EXPERIMENTAL RESULTS

YIELD

Yield data in bushels per acre are presented in Table 1 for each of the individual years and for the average of the 4 years.

Maximum yields were most frequently obtained when the plants were spaced 2 or 3 inches apart. The difference in yield between the 2- and 3-inch spacings was small. The 1-inch spacing usually outyielded the 4- and 5-inch spacings, but exceptions to this were noted, particularly in 1940 when both the 4- and 5-inch spacing equalled or exceeded the 1-inch spacing. In individual years, the varieties × spacings interaction was significant only in 1941, but this interaction was highly significant for the mean of the 4 years.

Within varieties, Mandell yielded the highest and Illini the lowest with 1-inch spacing over the 4-year period. Illini produced less with 1-inch spacing than with 2- or 3-inch spacing in each year, but Mandell was more variable and yielded highest with 3-inch spacing in 2 of the 4 years. Much of the varieties × spacings interaction may be attributed to the reaction of these two varieties and may have been caused by differential lodging. Illini lodged the most and Mandell the least of the group of varieties with 1-inch spacing.

From these data it is evident that the varieties studied reacted differently to different spacings, but yields were not so different with either 1-, 2-, or 3-inch spacings that, on the basis of yield alone, superior varieties would not be readily detected with variable stands with plants ranging from 1 to 3 inches apart for different varieties, or in different replications of the same variety. The small decreases in 4-year average yields due to spacing plants 4 or 5 inches apart in comparison to 1, 2, or 3 inches apart, and the obtaining of equally good or better yields on several occasions with the wider spacings, indicate that much variability may occur in stands and still permit finding the highest yielding varieties. The 4-year means likewise show that, with the exception of 1-inch spacing, there is little change in yield rank of the varieties with any of the spacings.

The results of the influence of spacing on lodging, height of plants, maturity, and seed size for the 4-year period are reported in Table 2.

LODGING

Lodging is affected by numerous characters of the plant and by environmental conditions. Lodging which does not exceed a score of 2 by the system used in this study is not considered serious.

The data show that varieties which may be classified as susceptible to lodging when the plants grow close together may appear as being resistant to lodging when spaced farther apart. Lodging was

TABLE 1.—*Influence of spacing plants in the row on the yield in bushels per acre of four varieties of soybeans grown at Lafayette, Ind., 1938–41, and the analysis of variance.*

Varieties	Distance between plants					
	1 in.	2 in.	3 in.	4 in.	5 in.	Mean
			1938			
Illini	35.3	40.6	40.8	35.1	33.3	37.0
Mandell	36.1	36.4	37.2	33.3	30.9	34.8
Dunfield	34.2	37.7	36.4	32.1	31.6	34.4
Mukden	34.0	38.1	38.4	33.1	31.7	35.1
Mean	34.9	38.2	38.2	33.4	31.9	
Significant difference, 3.5†						
			1939			
Illini	28.6	31.0	31.7	28.9	29.1	29.9
Mandell	36.0	32.4	32.6	31.5	29.9	32.5
Dunfield	33.3	31.3	31.4	31.8	28.3	31.2
Mukden	31.0	31.3	28.9	27.8	27.5	29.3
Mean	32.2	31.5	31.2	30.0	28.7	
Significant difference, 3.0†						
			1940			
Illini	31.7	35.6	35.7	35.8	35.8	34.9
Mandell	23.7	25.2	26.4	24.5	24.9	24.9
Dunfield	24.6	24.4	26.8	26.4	25.2	25.5
Mukden	28.5	29.9	29.5	28.3	28.8	29.0
Mean	27.1	28.8	29.6	28.8	28.7	
Significant difference, 2.4†						
			1941			
Illini	31.7	36.6	36.3	32.2	31.1	33.6
Mandell	35.0	33.3	30.6	28.7	27.5	31.0
Dunfield	28.4	31.5	30.6	28.1	27.1	29.1
Mukden	28.2	30.4	31.3	27.1	27.2	28.8
Mean	30.9	33.0	32.2	29.0	28.2	
Significant difference, 3.1†						
			4 years, 1938–41			
Illini	31.8	35.9	36.1	33.0	32.3	33.8
Mandell	32.7	31.8	31.7	29.5	28.6	30.9
Dunfield	30.1	31.2	31.3	29.6	28.0	30.0
Mukden	30.4	32.4	32.0	29.1	28.8	30.5
Mean	31.3	32.8	32.8	30.3	29.4	

Significant difference, 1.5†
Highly significant difference, 2.0‡

Analysis of Variance of Yields, 1938–41

Source of variation	Degrees of freedom	Mean squares
Years	3	654.62*
Varieties	3	234.66
Varieties × years	9	116.59**
Error (a)	24	11.26
Spacings	4	145.81**
Spacings × years	12	27.90**
Spacings × varieties	12	14.07**
Spacings × varieties × years	36	3.55
Error (b)	192	4.66

*Significant. **Highly significant.
†Bushels necessary for significance between spacings within varieties.
‡Bushels necessary for high significance between spacings within varieties.

TABLE 2.—*Four-year summary, 1938–41, of the influence of spacing soybean plants in the row on lodging, height, maturity, and seed size of four varieties of soybeans grown at Lafayette, Ind.*

Distance between plants, inches	Lodging*	Plant height, inches	Days to mature†	1,000 seed weight, grams
		Illini		
1	2.6	43	135	150
2	2.0	42	131	146
3	1.2	42	131	145
4	1.2	43	130	144
5	1.1	41	130	144
		Mandell		
1	1.9	39	134	160
2	1.4	39	132	157
3	1.1	38	131	156
4	1.2	38	131	160
5	1.3	38	131	159
		Dunfield		
1	2.4	36	136	165
2	1.7	37	133	166
3	1.5	36	132	161
4	1.7	36	131	162
5	1.6	36	131	162
		Mukden		
1	2.1	39	130	154
2	1.2	40	127	149
3	1.1	39	126	151
4	1.1	39	126	152
5	1.1	39	126	148
		Mean of All Varieties		
1	2.2	39	134	157
2	1.6	39	131	154
3	1.2	39	130	153
4	1.3	39	130	154
5	1.3	38	130	153

*Explanation of lodging values are given under materials and methods.
†Three-year data, 1938–40, inclusive.

most severe with 1-inch spacing and almost absent in the 3-, 4-, and 5-inch spacings, except with Dunfield. It is evident that in order to obtain comparable lodging ratings of different varieties, stands should be similar, or at least comparisons should not be made between thick stands and thin stands. Lodging resistance in varieties may be more readily detected under conditions of thick stands than with thin stands.

HEIGHT OF PLANTS

Varying the distance between the soybean plants had little influence on the height of the plants of any variety in this experiment. The tendency, however, was for plants spaced 5 inches apart to grow slightly shorter than when spaced closer together.

MATURITY

Spacing plants 2 to 5 inches apart hastened maturity in comparison with 1-inch spacing in each variety each year. The varieties averaged from 2 to 4 days earlier for spacings 2 to 5 inches apart in comparison with the 1-inch spacing.

These data show that, as with lodging, maturity data may not be comparable in variety trials if comparisons are made between thick stands and thin stands. An example of this difference is a comparison of the maturity of Mukden spaced 1 inch apart and Illini spaced 2, 3, 4, or 5 inches apart, in which case Illini and Mukden have approximately the same maturity, but by comparing the 2-, 3-, 4-, and 5-inch spacings of Mukden with the 1-inch spacing of Illini, Illini was 9 days later than Mukden in maturity. With equal stands Illini was about 5 days later than Mukden.

SEED SIZE

Spacing had little effect on the size of seed in the varieties studied. In most cases seed was slightly heavier when the plants were spaced 1 inch apart than when spaced wider apart, but this difference was not significant for the mean of the 4 years, and there was not a significant varieties × spacings interaction. Variation in size of seed was many times greater within varieties in different years than between spacings within varieties.

SUMMARY

Yield, lodging, height of plant, maturity, and seed size data are reported for four varieties of soybeans with plants spaced 1, 2, 3, 4, and 5 inches apart in nursery rows during the 4-year period 1938–41, inclusive.

The soybean varieties grown in this study differed somewhat in yield response when the plants were spaced 1, 2, 3, 4, and 5 inches apart in rows 30 inches apart. The varieties × spacings interaction was significant in one of the 4 years and was highly significant for the mean of the 4 years.

The least difference in yield, and usually the highest yield, was obtained when the plants were spaced 2 or 3 inches apart.

Variations in stand with plants from 1 to 3 inches apart in the row and occasional gaps of 4 or 5 inches between plants of an otherwise

thicker stand should not prevent superior varieties from expressing themselves on the basis of yield in varietal trials.

Thick planting is conducive to lodging and delayed maturity. Lodging and maturity data, on the basis of these studies, would not be comparable if varieties spaced 1 inch apart were to be compared with varieties spaced considerably further apart. There was practically no difference in maturity between 2-, 3-, 4-, or 5-inch spacings within a variety.

Spacing had little effect on the height of plants or the size of the seed under the conditions of this study.

JOURNAL

OF THE

American Society of Agronomy

VOL. 37 AUGUST, 1945 No. 8

A PORTABLE RUNOFF MEASURING DEVICE[1]

M. B. RUSSELL[2]

THE importance of measuring soil and water losses as a means of evaluating cropping systems and tillage operations as conservation practices is well recognized. To date, however, studies of this kind are confined largely to locations where permanent installations can be made and where sufficient labor is available to service the equipment following each runoff-producing storm (1).[3] Because of these constraints, runoff measurements on areas having a wide variety of soils and managements have not been made. The desirability of studies of this kind was readily apparent and was felt to be of sufficient importance to justify the development of equipment that would facilitate runoff studies on decentralized sites.

To meet the need for a simple portable runoff measuring device most adequately, a sampler should have the following characteristics: (a) No permanent structures should be required which will interfere with the utilization of the area after the completion of the experiment; (b) the time required to service the equipment after each storm should be comparable with that needed to service a rain gauge; (c) the device should be reliable, mechanically simple, and unaffected by trash; (d) the device must be capable of operating satisfactorily through intermittent storms having a wide range of runoff rates and silt concentrations; and (e) the amounts of both soil and water should be measured with precision comparable to that of existing equipment.

Of the several devices studied at the Iowa Experiment Station during the past three years, the tipping-bucket herein described most nearly meets the specifications listed above.

The principle of the counter-balanced tipping bucket has been used many times for measuring fluids. It has the advantage that it is mechanically simple, is unaffected by suspended debris, and readily cleans itself of soil deposited when the velocity of runoff is

[1]Journal Paper No. J-1280 of the Iowa Agricultural Experiment Station, Ames, Iowa, Project. No. 740. Received for publication April 9, 1945.

[2]Research Associate Professor, Department of Agronomy, Iowa State College, and Agent, Division of Research, Soil Conservation Service.

The author wishes to acknowledge the assistance and helpful suggestions provided by G. M. Browning, R. H. Heidel, J. R. Johnston, and others during the development of this device.

[3]Figures in parenthesis refer to "Literature Cited", p. 594.

lowered. The tilting-bucket has been used by Johnson (2) for measuring runoff from field plots. It is felt, however, that the method of collecting the aliquot and the mechanical simplicity of the device to be described here make it of greater usefulness than those previously reported.

DESCRIPTION OF THE SAMPLER

The schematic drawing in Fig. 1 illustrates the design and method of operation of the runoff sampler. The main bucket, A, is constructed of 18-gauge galvanized iron. It has a capacity of approximately 0.8 cubic feet. This bucket is pivoted on an axle, B, located at a point such that it is directly under the center of gravity of the bucket when nearly filled. The addition of more water causes the bucket to tip rapidly, thus bringing the aliquot collector, C, under the incoming stream of soil and water. When the collector, C, is filled, the excess runoff is discharged through the overflow orifice, D, into the counter-balancing bucket, E. The inflow of a small volume of runoff into E is sufficient to return the main bucket to its upright position. This action causes E to empty and causes the sampler, C, to discharge the runoff aliquot into the collecting funnel, F, from which it flows to a storage can. The number of cycles traversed by the bucket is tabulated by a tally counter, H, so mounted that it registers each tip of bucket A. The counter-weight, G, is adjusted so that a minimum of runoff is necessary in bucket E to cause it to tip. The oil-filled cylinder, not shown in Fig. 1 but visible in Fig. 2, serves as a damper to prevent bouncing of the main bucket after it discharges its contents. The sampler can be readily modified for runoff rate studies by providing a clock-driven chart on which each tipping cycle can be recorded by the displacement of the recording stylus.

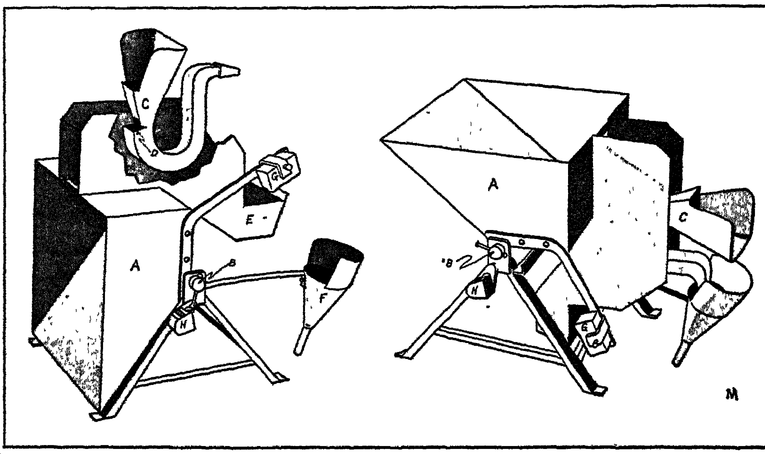

FIG. 1.—Schematic drawings of the runoff measuring device (left) in position to collect a sample of the runoff (right) in position to discharge sample.

Because of the lack of sufficient information regarding the intrastorm distribution of runoff rates and concentrations, it was con-

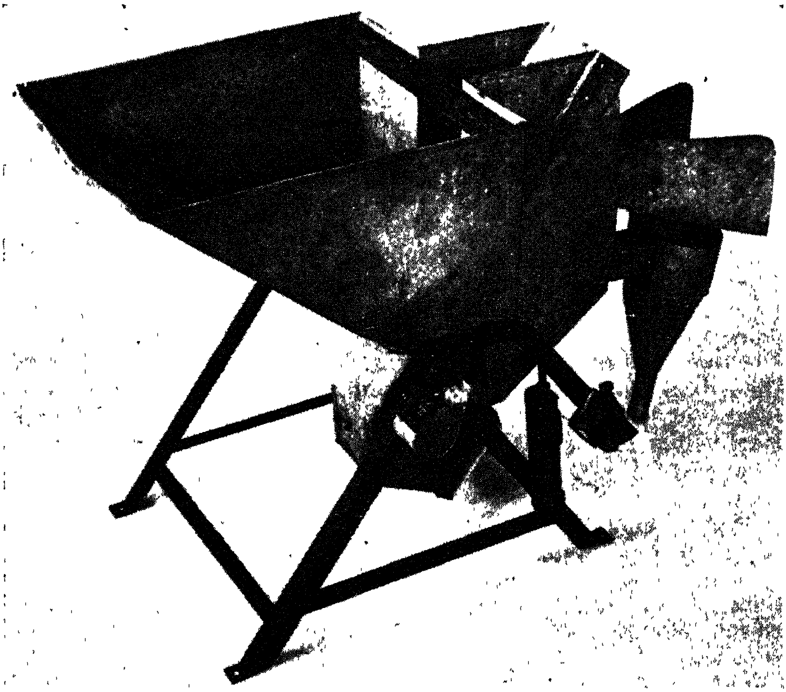

FIG. 2.—The runoff measuring device.

sidered advisable to test the device over a rather wide range of runoff rates and concentrations. For testing purpose, a 35 cubic foot steel horse tank equipped with two large four-bladed paddles was used as a storage tank for the soil suspension. A 2-inch pipe mounted on the bottom of the tank led the soil suspension through a gate valve and into the runoff sampler. Measured amounts of soil and water were placed in the tank. The soil was kept in suspension by the action of the two motor-driven paddles supplemented by hand stirring in the back water areas of the tank. Following each run the weight of soil remaining in the tank was determined and deducted from the amount initially added to give the actual weight of soil which had passed through the measuring device.

MEASUREMENT OF TOTAL RUNOFF VOLUME

The sampler is designed to measure the total volume of runoff and at the same time collect an aliquot from which the amount of soil can be calculated. It was decided first to determine the accuracy with which the device could measure the total volume of runoff. For this purpose measured volumes of water were run through the apparatus at several rates. The volumes of the individual aliquots were determined. For runoff rates less than 0.6 cubic feet per minute, the size of the aliquot was 604 ± 15 cc. This value was 656 ± 37 cc.

and 722 ± 28 cc for runoff rates between 0.6 and 1.3 cubic feet per minute and between 1.3 and 2.0 cubic feet per minute, respectively. Since the deviation of the mean value for several aliquots will vary inversely as the square root of the number of aliquots comprising the sample, it would be expected that at rates below 0.6 cubic feet per minute the standard deviation of samples composed of 16 aliquots would be approximately one-fourth of the standard deviation of the individual aliquots, or about 4 cc.

The volume of runoff required for each tipping cycle was calculated on the basis of 10 trials, involving a total volume of 150.6 cubic feet of runoff and included runoff rates ranging from 0.2 to 1.3 cubic feet per minute. The volume of runoff per trial varied from 7.9 to 31.6 cubic feet and the number of tipping cycles ranged from 8.5 to 31.5. The average volume per cycle was 0.978 ± .036 cubic feet. From these data it appears that the apparatus is capable of measuring the total volume of runoff well within 5% of the actual volume when the total volume amounts to 10 cubic feet or more.

MEASUREMENT OF SOIL LOSSES

The accuracy with which soil losses could be measured with the apparatus was determined, using suspensions whose densities ranged from 1.35 to 7.85 pounds of soil per cubic foot of suspension. More than 85% of the storms that have been measured at the Soil Conservation Experimental Farm at Clarinda, Iowa, produced runoff that would fall in this density range. Attempts were made to extend the calibration to higher densities, but the experimental difficulties described below became so great that these studies were discontinued. The results of these tests are shown in Table 1. The standard deviation of the calculated and actual soil weights for these nine trials is 7.2% of the actual value. In only one of the nine trials did the calculated weight of soil deviate from the actual amount by more than 10%. In that case, in which the calculated value exceeded the actual by 13%, the soil concentration was high. Under these conditions it was difficult to maintain a homogenous suspension in the mixing

TABLE 1.—*Calibration data for the portable runoff sampler.*

Trial No.	Volume of suspension, cu. ft.	Weight of added soil, lbs.	Av. density of suspension lbs. per cu. ft.	Average flow rate, cu. ft. per min.	Number of tipping cycles	Weight of soil in aliquot, grams	Total volume of aliquot, cc	Total soil calculated, lbs.	Error, per cent
1	31.6	87.3	2.75	0.6	31.5	883.0	18,975	90.4	+ 3.5
2	15.8	44.8	2.82	0.5	16.5	426.0	9,900	43.8	− 2.2
3	7.9	20.7	2.61	0.5	8.5	199.6	5,200	20.1	− 2.9
4	15.8	82.0	5.19	1.3	15.75	775.0	10,100	74.6	− 9.0
5	16.3	44.0	2.70	1.3	16.5	469.0	11,600	41.2	− 6.3
6	15.8	21.3	1.35	0.5	16.5	195.0	8,800	22.6	+ 6.1
7	15.8	85.7	5.43	0.5	16.75	799.0	8,900	92.5	+ 8.0
8	15.8	124.0	7.85	1.3	16.75	1,350	9,900	140.0	+13.0
9*	15.8	41.7	2.64	0.2	17.25	299.0	7,850	40.8	− 2.2

*The sampler used on this run was smaller than the one used previously; hence the lower average aliquot volume.

tank and it is quite probable that the 16 aliquots were insufficient to sample accurately such a wide range of instantenous concentrations that resulted.

In an attempt to evaluate the magnitude of the variation between the individual aliquots taken by the apparatus during a calibration trial, each of the 31 individual aliquots collected during trial No. 1 were dried and weighed. The weight of soil per aliquot ranged from 14.2 grams to 42.3 grams. The mean value was 28.5 grams and the standard deviation was 8.5 grams. On the basis of these data it was concluded that a minimum of 10 aliquots should be taken if the error in estimating the amount of soil were to be held below the 10% level. Although information is lacking, it is felt that under field conditions the runoff density probably does not fluctuate so widely or rapidly during a given storm as it did during these trials. Under such conditions it is reasonable to expect that this runoff sampler will evaluate soil losses with an accuracy at least as high as it did in these laboratory trials.

FIELD INSTALLATION AND SERVICING OF THE SAMPLER

The sampler herein described was designed for use on 1/100-acre plots. Undoubtedly it can be modified to handle runoff from areas of other sizes. For field size plots and watersheds a sampler of the type described by Kohnke and Hickok (3) will probably be more satisfactory. In its present form this sampler requires an operating head of 2.5 feet. Thus it is necessary to install the sampler sufficiently far down hill from the lower end of the plot so that the runoff which is delivered to the sampler from the concentrator through a 3-inch downspout pipe can be discharged into the sampler from a point 2.5 feet above the ground surface. In most cases this will require less than 50 feet of downspout pipe. On slopes of less than 5% it probably would be desirable to re-design the bucket so that a lower operating head could be utilized.

The sampler frame is bolted to four steel stakes firmly driven into the ground. The sampler can be easily leveled if the bolts are used as leveling screws. Half of a 50-gallon oil drum equipped with a cover and partially buried in the ground behind the sampler provides a convenient receptacle for the 5-gallon sample container. If the expected runoff is sufficiently large that the aliquot is likely to exceed 5 gallon, the sample container should be set in another larger water-tight vessel.

To service a field installation following a storm the operator first records the tally counter reading and then estimates the volume of runoff remaining in the bucket. This is of significance only when the number of tipping cycles has been small. The bucket is then manually tipped and cleaned. If the tally counter is operated during the cleaning process, its final reading should also be recorded as it will serve as the zero reading for the next storm. The volume of the aliquot is measured and recorded. If the aliquot exceeds ½ gallon, it is thoroughly mixed and run through a divider until a portion less than ½ gallon is obtained which is taken to the laboratory where the suspension density is determined by the usual method.

To calculate the total runoff, the number of tipping cycles, corrected for a residual runoff, is multiplied by a calibration factor determined for each sampler. This factor is merely the volume of runoff required for each tipping cycle. The total soil loss is calculated by multiplying the total runoff by its density as determined in the laboratory. It is apparent that the total aliquot volume does not enter into these calculations. Its only value is as a means of checking the tally counter reading.

LITERATURE CITED

1. GEIB, H. V. A new type of installation for measuring soil and water losses from control plots. Jour. Amer. Soc. Agron., 25:429–440. 1933.
2. JOHNSTON, C. N. Tilt buckets for measuring runoff and erosion. Agr. Eng., 23:161–162. 1942.
3. KOHNKE, HELMUT, and HICKOK, R. B. An automatic aliquot runoff sampler. Soil Sci. Soc. Amer. Proc. 8:444–447. 1944.

NITROGEN, PHOSPHORIC ACID, AND POTASH CONSUMPTION IN THE UNITED STATES, BY YEARS AND BY STATES, WITH PRELIMINARY FIGURES FOR 1944[1]

A. L. MEHRING, HILDA M. WALLACE, AND MILDRED DRAIN[2]

WARTIME demands for high food production and postwar planning have both increased the need for more detailed information on plant food[3] consumption than has been obtainable in the past. Such information is often of greatest value immediately after the close of the period covered.

Figures on the consumption of nitrogen, phosphoric acid, and potash have been published annually in recent years for California (4),[4] Indiana (21), Minnesota (9), Missouri (17), Ohio (19), and Wisconsin (7) by state authorities, and for all states for 1941 by this office (15). Similar figures for all states have been published also for the fiscal years ended June 30, 1934 (14), 1939 (13), and 1943 (11). No series of plant food consumption data for an extended period of years, however, has hitherto been available on a comparable basis, either for the United States or for most of the individual states. Although the number of tons of fertilizers distributed by Government agencies has been published (1, 22) and the total P_2O_5 disposed of in this way from 1935 to 1943 in each state was given in the August 1944 issue of the *Fertilizer Review*, the figures on the nitrogen and potash contents and those for P_2O_5 for individual years are not easily found.

The purpose of this paper is to give data regarding the consumption of the three principal plant nutrients by states for a series of years in order to show trends in usage and the effects of the war. The data for 1944 are preliminary and subject to revision in later publications.

HOW THE AMOUNTS WERE DETERMINED

The national figures, to be given later, are the sums of state figures for 1934 and later years. For earlier years they are largely estimates. State figures for 1934 to 1939, inclusive, were calculated from previously published data (12). Only the average figures for the 5-year period 1935–39 will be given here for individual states. Data for 1941

[1]Contribution from the Division of Soil and Fertilizer Investigations, U. S. Dept. of Agriculture, Agricultural Research Administration, Bureau of Plant Industry, Soils and Agricultural Engineering, Beltsville, Md. Received for publication June 1, 1945.

[2]Chemist and Assistant Statistical Clerks, respectively. The authors are indebted to W. F. Watkins and T. L. Jefferies, former and present Chief, respectively, Fertilizer Requirements Section, Office of Materials and Facilities, War Food Administration, for sending out the questionnaires upon which a part of this study is based.

[3]The term plant food will be used to mean nitrogen, phosphoric acid (P_2O_5), and potash (K_2O) as is customary in agriculture and industry rather than in the strictly scientific sense of the term.

[4]Figures in parenthesis refer to "Literature Cited", p. 608.

have been published (15) already in the desired form, and are merely copied here with some slight revisions. The 1940, 1942, 1943, and 1944 figures have not been published previously. The 1940 and 1942 data were obtained in the way described in earlier publications (12, 15).

The 1943 and 1944 state and national figures are based on questionnaires sent to all fertilizer manufacturers and producers of primary materials known to sell directly to retail dealers and farmers. The questionnaires were sent out in 1943 by W. F. Watkins, Chief, Fertilizer Requirements Section, U. S. War Food Administration, and in 1944 by T. L. Jefferies, who succeeded him. Properly executed returns, covering about 95% of the tonnage, were obtained for each of the three 6-month periods between July 1, 1942, and December 31, 1943. For the first half of 1944 only 89 companies, which operate one small plant each, out of a total of 696 known producers operating 1,025 plants failed to report. Some of these may have gone out of business. Almost one-third of the companies that did not report are located in Georgia. The returns were tabulated and analyzed in this office.

The tonnages of nitrogen, phosphoric acid, and potash were determined from the tons of each kind of fertilizer sold and the plant food content of that kind in the State in question, as given in the state fertilizer analysis bulletins. The results for 1943 and the first half of 1944 were largely determined from the questionnaires mentioned above. The plant food consumption in the fall of 1944 was also actually determined for 12 states, Puerto Rico, and Hawaii. The companies selling in Hawaii have already reported the fall sales to us. The necessary state tonnage data for the 1944 fall season were obtained from the following sources: California (5), Delaware,[5] Florida (6), Kansas (10), Kentucky,[6] Maryland (3), New Hampshire (20), New Jersey (2), New Mexico,[7] North Carolina (18), South Carolina (23), and Wisconsin (8). Basic data for Puerto Rico were provided by L. A. Izquierdo, Commissioner of Agriculture and Commerce, Government of Puerto Rico.

The plant food distributed by government agencies was computed from the tonnages of materials as reported by the Agricultural Adjustment Agency (1) and by the Tennessee Valley Authority (22) and the estimated plant food content of each material. T.V.A. figures are for fiscal years, ending June 30. Available calendar-year figures indicate that the T.V.A. distribution of plant food was approximately the same on either a fiscal or calendar year basis. At any rate the errors are too small to affect seriously the state or national totals.

The tonnage so far definitely accounted for in 1944 is 10,346,359. This is thought to be about 85% of the total. The unreported tonnage for 1944 was estimated for each state, for which reports were missing, from tax tag sales or information gained from competent observers

[5]Personal letter from Claud E. Phillips, Department of Agronomy, University of Delaware.

[6]Personal letter from H. R. Allen, Kentucky Department of Feed and Fertilizer Control.

[7]Personal letter from R. W. Ludwick, New Mexico Field and Fertilizer Control Office.

in each state as to the size of the 1944 tonnage in comparison with that of 1943. The estimates of the quantities of plant nutrients were then calculated from these tonnages and the estimated kinds of fertilizers sold.

It is felt that the figures given in the tables are quite accurate for 1943 and fairly reliable for the other years. The error for the individual results for 1943 and 1944 could hardly exceed 5% of the value given in any instance; that for the national totals 2.5%. The figures given for the earlier years are the least accurate, but the maximum error in any case is not likely to be greater than 10%.

FERTILIZER CONSUMPTION OVER LONG PERIOD

In 1860, about 32,000 tons of commercial fertilizers were sold in the United States. Sales had increased to 1,400,000 tons in 1890. Fertilizer usage continued to increase steadily to a maximum of 7,194,000 tons in 1914. But from 1914 to 1939 consumption fluctuated between 5 and 8 million tons, with the exception of a few years of unusual conditions. In the 30 years prior to 1940 average consumption was 6⅔ millon tons annually. Starting in 1940, new high records have been established in each year. The latest record is 12,468,000 tons in 1944, and it is highly probable that this will be exceeded in 1945. The total consumption of fertilizers and their calculated plant nutrient contents are given in Table 1 by decades from 1900 to 1930, and annually for more recent years.

TABLE 1.—*Fertilizer and plant food consumption in the United States, 1900, 1910, 1920, and 1930–44.**

Year	All fertilizers, 1,000 tons	Plant food, tons				Calculated average plant food content of all fertilizer, %			
		Nitrogen	Phosphoric acid	Potash	Total	N	P_2O_5	K_2O	Total
1900	2,730	62,000	246,200	86,500	394,700	2.27	9.02	3.17	14.46
1910	5,547	145,900	499,200	211,000	856,100	2.63	9.00	3.80	15.43
1920	7,296	227,800	660,100	257,500	1,145,400	3.12	9.05	3.53	15.70
1930	8,425	376,600	792,800	353,800	1,523,200	4.47	9.41	4.20	18.08
1931	6,541	300,900	610,900	274,700	1,186,500	4.60	9.34	4.20	18.14
1932	4,545	213,600	412,900	191,600	818,100	4.70	9.08	4.22	18.00
1933	5,110	240,200	463,500	222,300	926,000	4.70	9.07	4.35	18.12
1934	5,794	275,286	529,529	262,699	1,067,514	4.75	9.14	4.53	18.42
1935	6,534	311,816	597,321	306,567	1,215,704	4.77	9.14	4.69	18.60
1936	7,222	350,390	672,849	350,075	1,373,314	4.85	9.32	4.85	19.02
1937	8,433	411,482	793,943	416,024	1,621,449	4.88	9.41	4.93	19.22
1938	7,758	384,056	743,657	393,450	1,521,163	4.95	9.59	5.07	19.61
1939	7,993	398,207	789,414	409,077	1,596,698	4.98	9.88	5.12	19.98
1940	8,656	419,093	912,255	435,016	1,766,364	4.85	10.57	5.04	20.46
1941	9,381	458,051	993,571	466,748	1,918,370	4.88	10.59	4.98	20.45
1942	10,131	398,563	1,130,576	547,022	2,076,161	3.93	11.16	5.40	20.49
1943	11,754	505,632	1,243,306	643,177	2,392,115	4.30	10.58	5.47	20.35
1944	12,468	626,208	1,305,410	641,722	2,573,340	5.02	10.47	5.15	20.64

*Including Hawaii, Puerto Rico, and government-distributed fertilizers.

Of the 12,468,000 tons consumed in 1944, 12,184,000 tons were used in the continental United States and 284,000 tons in Hawaii and Puerto Rico. In the continental United States commercial establishments sold 11,298,000 tons, the Agricultural Adjustment Agency disposed of 844,000 tons, and the Tennessee Valley Authority distributed 42,000 tons. Government distribution started in 1935 and increased each year to a maximum of 1,139,000 tons in 1942. It then decreased to 1,024,571 tons in 1943 and to 886,453 tons in 1944.

Commercial concerns in 1944 sold 11,568,000 tons, of which 8,681,000 tons, or 75.0%, were mixed fertilizers and 2,887,000 tons, or 25.0%, were separate or basic fertilizer materials. In 1942 and 1943 mixed fertilizers constituted 75.7 and 75.2% of the totals, respectively. In most years previous to 1942, and since 1930, mixed fertilizers constituted close to 70% of the total.

PLANT FOOD CONSUMPTION AND CONTENT DURING PRESENT CENTURY

While fertilizer tonnage increased 115.2% in the past 10 years, fertilizer nitrogen consumption increased 127.5%, phosphoric acid 146.5%, and potash 144.3%. Most of the fertilizer distributed by the government consisted of phosphates. Without this tonnage the increase in consumption of phosphoric acid is only 114.9%. Therefore, the commercial delivery in the past decade increased most for potash. In spite of this fact the potash tonnage was approximately the same in 1944 as in 1943, although nitrogen consumption increased by 118,000 tons and phosphoric acid by 62,000 tons. This was not due to any shortage of potash. Actual deliveries of potash to fertilizer manufacturers during 1944 as reported by the American Potash Institute were about 60,000 tons more than can be accounted for in the fertilizers sold in the same period after allowance is made for other sources of potash. The trends in consumption of the three principal plant nutrients with the passage of time are illustrated in Fig. 1.

The calculated average total plant food content of all fertilizers increased from 14.46% in 1900 to 18.08% in 1930 and to 20.64% in 1944, as may be seen in Table 1. Since 1940 this total has remained fairly constant in spite of the fact that the plant food content of mixed fertilizers has changed from a total content of 19.9% in 1940 to about 21.0% in 1944. The rapid rise in P_2O_5 content from 1937 to 1942 was largely due to the increasing tonnage of superphosphates distributed by the government. In 1942 war-induced changes in our economy began to influence fertilizer composition. The average nitrogen content went down and the average P_2O_5 and K_2O went up abruptly. A shortage of nitrogen for fertilizer use developed in 1942 due to demands for munitions. This difficulty was met by prohibiting the use of nitrogen for certain nonessential uses such as on lawns, and by restricting its usage on certain crops. Grades of mixed fertilizers containing less nitrogen and more of the other nutrients were selected at conferences attended by government and industry representatives with a view to making the most effective use of the

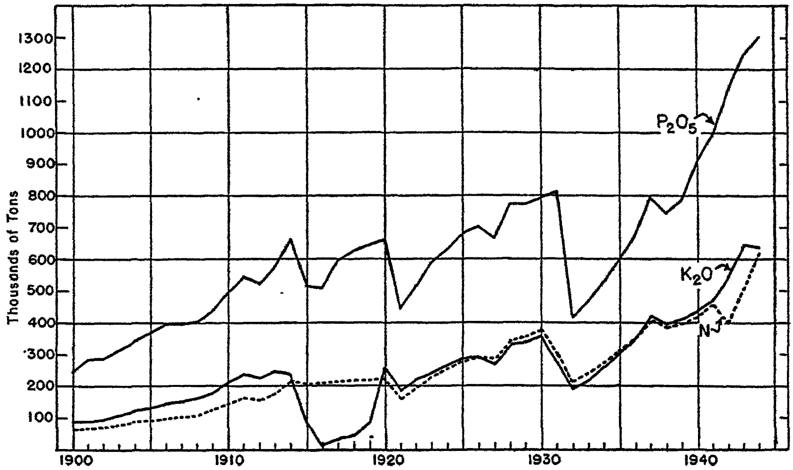

FIG. 1.—Consumption of nitrogen, phosphoric acid, and potash as commercial fertilizer in the United States during the period of 1900–44.

short supply. In 1943 additional production from a number of new plants made more nitrogen available. Consequently new grades were adopted and the restrictions were relaxed. Last year further steps were taken in the same direction.

REGIONAL AND STATE CONSUMPTION IN RECENT YEARS

The quantities of nitrogen, phosphoric acid, and potash consumed in each state and territory are given in Table 2 for recent years and as an average for five pre-war years. The consumption in all territories other than Hawaii and Puerto Rico is only a few hundred tons annually.

This country used 7.4% more plant food in 1944 than in 1943, but the increase was far from uniform throughout the various regions. The percentage increases are as follows: Western 30.6%, West North Central 29.4%, the territories 22.4%, East North Central 16.9%, Middle Atlantic 7.7%, South Central 3.6%, and the South Atlantic 1.0%. On the other hand, the New England states used 0.9% less. Thus it is clear that a large part of the increase in 1944 over 1943 was in the regions where relatively little commercial fertilizer was used in the past.

When compared with the 5-year, 1935–39, average the changes in usage are quite different. All regions of the continental United States consumed much more in 1944 than in pre-war years. Usage was 367% of pre-war in the West North Central, 243% in the Western, 236% in the East North Central, 204% in the South Central, 156% in the Middle Atlantic, 151% in New England, 150% in the South Atlantic, and 100% in the territories. The increase in Iowa is outstanding. The average total consumption of nitrogen, phosphoric acid, and potash in the 5-year period 1935–39 is 2,147 tons. This state used 16,729 tons in 1944, or about 8 times as much as in pre-war years. Of this quantity 3,971 tons of P_2O_5 was distributed by the

TABLE 2.—*Consumption by Regions and States of nitrogen (N), phosphoric acid (P_2O_5) and potash (K_2O) in recent years.*[1]

Region and state	Year	Nitrogen, tons	Phosphoric acid, tons	Potash, tons
Continental U. S.				
	Av. 1935–39	337,338	703,926	353,280
	1940	378,543	895,997	404,831
	1941	418,485	978,192	438,139
	1942	374,639	1,119,549	526,960
	1943	480,415	1,232,278	624,266
	1944	594,144	1,288,302	619,966
New England				
	Av. 1935–39	16,466	31,947	26,854
	1940	16,957	41,949	28,889
	1941	18,383	57,222	31,994
	1942	18,272	48,936	40,478
	1943	20,213	53,152	44,178
	1944	24,864	49,935	41,309
Maine				
	Av. 1935–39	7,663	14,113	16,494
	1940	8,104	18,439	17,732
	1941	9,120	21,196	20,216
	1942	8,640	22,197	23,820
	1943	10,902	25,073	28,114
	1944	13,538	22,190	27,468
New Hampshire				
	Av. 1935–39	747	1,910	975
	1940	649	4,009	965
	1941	744	4,972	1,073
	1942	847	3,649	1,888
	1943	863	3,347	1,689
	1944	975	2,769	1,342
Vermont				
	Av. 1935–39	610	4,105	1,004
	1940	618	5,657	1,154
	1941	696	14,113	1,191
	1942	756	6,893	3,423
	1943	788	5,976	1,716
	1944	817	6,669	1,195
Massachusetts				
	Av. 1935–39	3,761	5,974	4,023
	1940	3,640	7,227	4,322
	1941	3,789	8,585	4,577
	1942	3,924	8,340	5,733
	1943	3,443	9,413	6,006
	1944	4,558	9,934	5,388
Rhode Island				
	Av. 1935–39	588	1,073	730
	1940	583	1,349	770
	1941	628	1,861	878
	1942	653	1,645	1,022
	1943	607	1,854	1,211
	1944	807	1,770	1,214
Connecticut				
	Av. 1935–39	3,097	4,772	3,628
	1940	3,363	5,268	3,946
	1941	3,406	6,495	4,059
	1942	3,452	6,202	4,592
	1943	3,610	7,419	5,442
	1944	4,169	6,603	4,702

TABLE 2.—*Continued.*

Region and state	Year	Nitrogen, tons	Phosphoric acid, tons	Potash, tons
Middle Atlantic				
	Av. 1935–39	35,090	128,474	59,780
	1940	36,144	160,589	62,482
	1941	39,694	181,464	70,981
	1942	38,194	191,734	79,513
	1943	41,847	192,797	89,595
	1944	55,280	204,564	88,890
New York				
	Av. 1935–39	12,141	39,949	14,667
	1940	11,615	62,038	16,498
	1941	12,914	70,682	17,776
	1942	13,520	70,020	20,553
	1943	15,055	66,936	24,610
	1944	19,676	64,805	23,764
New Jersey				
	Av. 1935–39	7,556	15,392	12,241
	1940	8,123	15,628	12,242
	1941	8,593	18,089	15,729
	1942	9,391	21,823	16,425
	1943	8,631	25,110	18,281
	1944	11,234	27,011	19,774
Pennsylvania				
	Av. 1935–39	8,055	42,427	16,749
	1940	8,518	47,477	17,837
	1941	9,352	54,434	20,170
	1942	7,831	58,954	22,638
	1943	10,063	59,681	25,761
	1944	13,703	70,231	24,012
Delaware				
	Av. 1935–39	1,062	3,704	2,908
	1940	1,132	3,484	2,844
	1941	1,111	3,556	2,829
	1942	894	3,918	3,268
	1943	1,128	4,856	3,649
	1944	1,369	5,305	3,509
Maryland				
	Av. 1935–39	4,855	17,039	11,019
	1940	5,258	16,576	10,629
	1941	5,846	18,654	11,761
	1942	5,171	21,320	13,942
	1943	5,530	25,655	14,342
	1944	7,433	26,308	15,271
District of Columbia				
	Av. 1935–39	76	180	63
	1940	83	198	70
	1941	92	220	78
	1942	86	250	70
	1943	64	195	85
	1944	67	185	77
West Virginia				
	Av. 1935–39	1,345	9,783	2,133
	1940	1,415	15,188	2,362
	1941	1,786	15,829	2,638
	1942	1,301	15,449	2,617
	1943	1,376	10,364	2,867
	1944	1,798	10,719	2,482

TABLE 2.—*Continued.*

Region and state	Year	Nitrogen, tons	Phosphoric acid,* tons	Potash, tons
South Atlantic				
	Av. 1935–39	159,653	269,789	156,159
	1940	168,440	287,553	173,505
	1941	176,764	298,590	184,150
	1942	163,989	346,574	200,585
	1943	204,254	407,149	256,859
	1944	234,726	398,803	243,982
Virginia				
	Av. 1935–39	15,206	41,965	15,582
	1940	15,251	50,710	17,452
	1941	15,800	54,122	18,200
	1942	11,553	57,763	18,210
	1943	16,817	61,090	25,668
	1944	20,541	65,263	25,542
North Carolina				
	Av. 1935–39	47,373	84,210	46,730
	1940	48,453	87,937	50,176
	1941	47,567	86,338	49,940
	1942	52,206	106,894	66,998
	1943	61,118	118,058	75,196
	1944	68,204	116,001	69,913
South Carolina				
	Av. 1935–39	34,557	47,960	28,654
	1940	38,329	48,316	37,391
	1941	40,406	47,235	36,277
	1942	36,123	51,150	38,289
	1943	45,883	64,950	46,906
	1944	50,375	63,413	40,560
Georgia				
	Av. 1935–39	35,640	59,647	31,320
	1940	39,509	65,093	35,162
	1941	41,929	70,245	37,494
	1942	36,932	86,971	36,809
	1943	47,685	109,440	53,574
	1944	57,114	96,217	49,404
Florida				
	Av. 1935–39	26,877	36,007	33,873
	1940	26,898	35,497	33,324
	1941	31,062	40,650	42,239
	1942	27,175	43,796	40,279
	1943	32,751	53,611	55,515
	1944	38,492	57,909	58,563
East North Central				
	Av. 1935–39	17,048	101,621	50,440
	1940	21,834	127,556	70,398
	1941	24,479	144,611	78,205
	1942	18,770	197,112	117,019
	1943	25,529	204,855	112,541
	1944	40,072	228,804	131,939
Ohio				
	Av. 1935–39	7,471	45,428	17,512
	1940	8,901	48,448	22,744
	1941	10,092	54,143	26,493
	1942	7,377	61,576	33,085
	1943	9,755	69,897	36,476
	1944	13,667	72,744	38,150

TABLE 2.—*Continued.*

Region and state	Year	Nitrogen, tons	Phosphoric acid, tons	Potash, tons
Indiana				
	Av. 1935–39	4,383	22,603	17,844
	1940	5,354	38,934	24,990
	1941	5,741	36,404	24,514
	1942	3,958	44,941	32,793
	1943	6,394	51,377	35,452
	1944	8,432	60,273	39,695
Illinois				
	Av. 1935–39	1,059	4,340	2,659
	1940	1,834	6,912	4,323
	1941	2,222	11,253	5,270
	1942	1,651	19,348	7,117
	1943	2,119	21,300	10,247
	1944	4,500	26,763	17,889
Michigan				
	Av. 1935–39	3,083	17,250	8,989
	1940	4,197	21,770	12,642
	1941	4,715	27,238	13,510
	1942	3,769	38,276	22,085
	1943	5,007	33,035	18,139
	1944	7,982	38,965	19,661
Wisconsin				
	Av. 1935–39	1,052	5,000	3,436
	1940	1,548	11,492	5,699
	1941	1,709	15,573	8,418
	1942	2,015	32,971	21,939
	1943	2,254	29,246	12,227
	1944	5,491	30,059	16,544
West North Central				
	Av. 1935–39	1,870	18,588	3,831
	1940	1,971	25,612	4,649
	1941	2,064	32,886	5,483
	1942	2,085	45,315	7,940
	1943	2,479	54,362	11,752
	1944	4,239	69,015	14,933
Minnesota				
	Av. 1935–39	289	1,827	1,271
	1940	449	3,770	1,494
	1941	391	7,206	1,730
	1942	638	8,760	2,514
	1943	705	9,228	3,757
	1944	1,037	13,292	3,940
Iowa				
	Av. 1935–39	142	1,405	600
	1940	263	2,720	882
	1941	370	4,454	1,240
	1942	487	7,639	2,437
	1943	478	10,019	3,135
	1944	1,033	11,643	4,053
Missouri				
	Av. 1935–39	1,269	11,756	1,772
	1940	1,062	13,193	2,029
	1941	1,091	14,429	2,319
	1942	805	19,725	2,872
	1943	1,099	24,940	4,414
	1944	1,858	30,843	6,200

TABLE 2.—*Continued.*

Region and state	Year	Nitrogen, tons	Phosphoric acid, tons	Potash, tons
North Dakota				
	Av. 1935–39	4	174	5
	1940	14	624	19
	1941	21	735	21
	1942	24	822	24
	1943	25	925	89
	1944	18	763	182
South Dakota				
	Av. 1935–39	1	67	1
	1940	3	209	3
	1941	5	200	5
	1942	6	200	5
	1943	5	166	11
	1944	2	192	18
Nebraska				
	Av. 1935–39	20	519	7
	1940	20	873	17
	1941	18	720	18
	1942	24	960	24
	1943	29	620	47
	1944	10	1,000	4
Kansas				
	Av. 1935–39	145	2,840	175
	1940	160	4,223	205
	1941	168	5,142	150
	1942	101	7,209	64
	1943	138	8,464	299
	1944	281	11,282	536
South Central				
	Av. 1935–39	77,587	126,849	47,594
	1940	99,073	210,576	56,057
	1941	112,838	216,898	56,921
	1942	98,925	242,828	67,696
	1943	131,540	268,860	94,267
	1944	159,651	268,145	85,558
Kentucky				
	Av. 1935–39	2,213	23,329	2,916
	1940	2,124	63,253	3,347
	1941	2,374	57,100	3,876
	1942	2,782	57,383	5,066
	1943	2,997	44,420	7,234
	1944	6,435	43,283	8,689
Tennessee				
	Av. 1935–39	3,197	19,014	4,327
	1940	4,375	37,960	5,288
	1941	4,569	41,766	5,163
	1942	5,229	44,977	6,972
	1943	7,943	45,164	12,343
	1944	11,584	47,021	11,859
Alabama				
	Av. 1935–39	29,328	43,442	21,449
	1940	33,233	55,574	23,223
	1941	36,126	55,324	22,709
	1942	30,135	64,855	23,419
	1943	34,763	80,850	31,629
	1944	45,063	79,244	28,442

TABLE 2.—*Continued.*

Region and state	Year	Nitrogen, tons	Phosphoric acid, tons	Potash, tons
Mississippi				
	Av. 1935–39	22,620	17,362	8,876
	1940	31,197	17,417	9,468
	1941	37,077	18,494	8,756
	1942	33,659	27,589	12,412
	1943	51,225	34,184	15,543
	1944	51,474	30,346	12,416
Arkansas				
	Av. 1935–39	4,227	4,314	2,525
	1940	8,707	12,151	5,102
	1941	9,811	13,695	5,275
	1942	7,111	13,355	8,246
	1943	10,953	17,545	10,749
	1944	12,741	18,635	9,145
Louisiana				
	Av. 1935–39	11,768	9,929	4,132
	1940	12,745	10,918	4,999
	1941	15,579	14,893	5,806
	1942	12,958	15,842	6,168
	1943	14,663	19,273	8,108
	1944	19,465	20,766	7,301
Oklahoma				
	Av. 1935–39	253	729	303
	1940	167	542	187
	1941	279	753	321
	1942	350	1,983	407
	1943	320	2,294	529
	1944	610	2,768	606
Texas				
	Av. 1935–39	3,981	8,730	3,066
	1940	6,525	12,761	4,443
	1941	7,023	14,873	5,015
	1942	6,701	16,844	5,006
	1943	8,676	25,130	8,132
	1944	12,279	26,102	7,100
Western				
	Av. 1935–39	29,624	26,658	8,622
	1940	34,124	42,162	8,851
	1941	44,263	46,521	10,405
	1942	34,404	47,060	13,729
	1943	54,553	51,103	15,074
	1944	75,312	69,036	13,355
Montana				
	Av. 1935–39	58	1,669	42
	1940	56	1,771	45
	1941	45	1,800	45
	1942	50	1,890	5
	1943	32	2,484	11
	1944	75	3,075	3
Idaho				
	Av. 1935–39	47	1,961	81
	1940	4	3,091	8
	1941	4	3,873	15
	1942	342	3,613	146
	1943	505	3,909	264
	1944	961	6,484	180

TABLE 2.—*Continued.*

Region and state	Year	Nitrogen, tons	Phosphoric acid, tons	Potash, tons
Wyoming				
	Av. 1935–39	10	792	10
	1940	0	945	0
	1941	0	765	0
	1942	0	900	0
	1943	4	767	6
	1944	10	1,192	2
Colorado				
	Av. 1935–39	101	978	54
	1940	260	1,311	201
	1941	263	1,635	141
	1942	248	2,184	195
	1943	277	2,593	145
	1944	850	3,056	60
New Mexico				
	Av. 1935–39	72	752	7
	1940	80	1,111	5
	1941	132	1,441	20
	1942	89	1,463	4
	1943	68	1,613	23
	1944	127	2,095	22
Arizona				
	Av. 1935–39	750	881	33
	1940	663	1,158	39
	1941	1,117	2,275	38
	1942	1,220	1,524	50
	1943	2,164	2,547	92
	1944	2,205	2,520	472
Utah				
	Av. 1935–39	27	1,017	13
	1940	31	1,189	15
	1941	28	2,532	14
	1942	40	1,706	10
	1943	148	1,695	26
	1944	301	3,374	2
Nevada				
	Av. 1935–39	18	109	9
	1940	10	175	10
	1941	10	175	10
	1942	6	240	6
	1943	5	91	1
	1944	20	120	6
Washington				
	Av. 1935–39	1,457	2,607	1,444
	1940	1,954	8,670	1,445
	1941	1,932	6,068	1,540
	1942	3,755	5,908	3,158
	1943	2,833	6,334	2,326
	1944	5,162	7,087	1,750
Oregon				
	Av. 1935–39	1,077	1,823	895
	1940	1,872	4,839	1,231
	1941	1,850	4,921	1,240
	1942	1,852	4,345	1,241
	1943	2,223	5,628	1,374
	1944	3,143	5,556	1,080

TABLE 2.—*Concluded.*

Region and state	Year	Nitrogen, tons	Phosphoric acid, tons	Potash, tons
California				
	Av. 1935–39	26,007	14,069	6,034
	1940	29,194	17,902	5,852
	1941	38,882	21,036	7,342
	1942	26,802	23,287	8,914
	1943	46,294	23,442	10,806
	1944	62,458	34,477	9,778
Non-Contiguous Territories				
	Av. 1935–39	33,898	15,612	21,796
	1940	40,550	16,258	30,185
	1941	39,566	15,379	28,609
	1942	23,924	11,217	20,032
	1943	28,217	11,046	18,911
	1944	32,064	17,108	21,756
Hawaii				
	Av. 1935–39	17,610	7,644	8,871
	1940	17,043	5,646	11,043
	1941	18,125	5,625	11,125
	1942	14,315	5,726	10,880
	1943	13,714	4,632	8,642
	1944	12,464	5,508	7,756
Puerto Rico				
	Av. 1935–39	16,288	7,968	12,925
	1940	23,507	10,612	19,142
	1941	21,441	9,754	17,484
	1942	9,609	5,491	9,152
	1943	14,503	6,414	10,269
	1944	19,600	11,600	14,000
Total United States				
	Av. 1935–39	371,236	719,538	375,076
	1940	419,093	912,255	435,016
	1941	458,051	993,571	466,748
	1942	398,563	1,130,766	546,992
	1943	508,632	1,243,324	643,177
	1944	626,208	1,305,410	641,722

[1]Including fertilizers distributed by Government, dried manures, and rock phosphate. The calculations are based on the total P_2O_5 content of bonemeal and natural organics and the available P_2O_5 of all other fertilizers.

government, but even without this tonnage the rate of growth is very rapid. Some other states with a very rapid increase in plant nutrient consumption on a percentage basis in recent years are Wisconsin, Illinois, Minnesota, Arkansas, Texas, Idaho, and Arizona. The consumption per acre of cultivated land, however, is still very small in all these states. On an actual tonnage basis, however, increased usage in South Atlantic and South Central regions is greatest, especially from 1942 to 1943. Nearly all states along the coasts used more nitrogen and less potash in 1944 than in 1943. The following states used a little less total plant food in 1944 than in 1943: Maine, New Hampshire, Connecticut, South Carolina, Georgia, North Dakota, and Mississippi.

Fertilizer consumption both in Puerto Rico and Hawaii has been reduced by war conditions. Puerto Rico suffered most in 1942 when

insufficient shipping space was available to carry fertilizer materials to the island. In 1944, however, additional boat space to Puerto Rico was again obtainable for this purpose. Although in Hawaii consumption did not drop off so drastically in 1942, it has declined somewhat in each year since then.

In 1945 the commercial demand for fertilizer nitrogen will probably be about 650,000 tons, that for phosphoric acid 1,250,000 tons, and that for potash 675,000 tons.

SUMMARY

The United States in 1944 consumed 12,468,000 tons of fertilizers which contained 626,000 tons of nitrogen, 1,305,000 tons of phosphoric acid, and 642,000 tons of potash. Commercial organizations sold directly to farmers and gardeners 591,000 tons of nitrogen, 1,121,000 tons of phosphoric acid, and 620,000 tons of potash in the continental part of the country and 32,000 tons of nitrogen, 17,000 tons of phosphoric acid, and 22,000 tons of potash in the non-contiguous territories. Government agencies disposed of 3,164 tons of nitrogen, 167,569 tons of phosphoric acid, and 17 tons of potash.

Nitrogen consumption in 1944 was 120,000 tons greater than in 1943, that of P_2O_5 was 60,000 tons greater, and that of K_2O was about the same. Compared with 1934, however, potash consumption increased more than that of either of the others. Total plant food consumption from 1943 to 1944 increased most on a percentage basis in the Western and West North Central states. The average increase in these states was 30%. The total tonnages of plant food used in the New England and South Atlantic states remained almost the same in 1944 as in 1943, although a few states used slightly less.

LITERATURE CITED

1. AGRICULTURAL ADJUSTMENT AGENCY. Summary of conservation materials ordered and delivered during calendar year 1944. 1945.
2. BEAR, FIRMAN E. Fertilizer sales in New Jersey in 1944. Soils Dept., Rutgers Univ. 1945.
3. BOPST, L. E. Maryland fertilizer facts for 1944. Md. Inspection Service. 1945.
4. COX, ALVIN J. Commercial fertilizers, agricultural minerals, 1943. Calif. Bur. Chem. Spec. Pub. 203. 1944.
5. ———. Commercial fertilizer sales as reported to date for quarters ended Sept. 30, 1944, and Dec. 31, 1944. Calif. Bur. Chem. Announcements FM-103, 1944, and FM-104, 1945.
6. FLORIDA DEPARTMENT OF AGRICULTURE. Consumption of mixed fertilizers and fertilizer materials by counties of Florida. Monthly Repts. Fert. Statistical Div. 1944 and 1945.
7. GRIEM, W. B. Wisconsin fertilizer statistics, 1943. Wis. State Dept. Agr. Bul. 246. 1944.
8. ———. Wisconsin 1944 commercial fertilizer summary. Wis. State Dept. Agr. 1945.
9. HALVORSON, H. A. Fertilizer analyses and registrations, 1944. Minn. Dept. Agr., Dairy and Food. 1945.
10. KANSAS STATE BOARD AGRICULTURE. Tonnage of commercial fertilizer reported by manufacturers as shipped to Kansas during the year 1944, by counties. 1945.
11. MEHRING, A. L., BAILEY, ELIZABETH, and WALLACE, HILDA M. A survey of fertilizer grades and plant food consumption in the United States for the year ended June 30, 1943. Proc. 20th Ann. Conven. Nat. Fert. Assoc. Part 2. 1944.

12. ———— and DEMING, LOLA. Average plant food content of fertilizers consumed in the United States and its subdivisions, 1934–1939. Amer. Fert., 93, No. 4:5–11; 22–26. 1940.
13. ————, DEMING, LOLA, and WILLETT, HERBERT. A survey of plant food consumption in the United States in the year ended June 30, 1939. Nat. Fert. Assoc. 1940.
14. ———— and SMALLEY, H. R. A survey of plant food consumption in the United States for the year ended June 30, 1934. Proc. 11th Ann. Conven. Nat. Fert. Assoc., 137–203. 1935.
15. ———— and VINCENT, GRACE. Fertilizer consumption in 1941 and trends in usage. U. S. D. A. Circ. 689. 1943.
16. MICHIGAN STATE COLLEGE SOIL SCIENCE DEPARTMENT. Tonnage of different grades of fertilizer sold in Michigan, 1944. 1945.
17. MILLER, M. F., HAIGH, L. D., COWAN, E. W., and LONG, J. H. Fertilizer inspection analysis and use, 1943. Mo. Agr. Exp. Sta. Bul. 480. 1944.
18. NORTH CAROLINA DEPARTMENT OF AGRICULTURE. Fertilizer sales by grades in order of tonnage, July 1, 1944–Dec. 31, 1944. 1945.
19. OHIO STATE UNIVERSITY, DEPARTMENT OF AGRONOMY. Fertilizer sales in Ohio in 1943. 1944.
20. PRINCE, FORD S. Grade-tonnage survey, 1944, New Hampshire. N. H. Agr. Expt. Sta. 1945.
21. QUACKENBUSH, F. W., *et al.* Inspection of commercial fertilizers. Purdue Univ. Agr. Exp. Sta. Circ. 299. 1944.
22. TENNESSEE VALLEY AUTHORITY. Annual report for the fiscal year ended June 30, 1944. 1945.
23. WEBB, H. J. Tonnage report July 1, 1944, through Dec. 31, 1944. Dept. Fert. Insp. and Anal., Clemson College, S. C. 1945.

PROGRESS REPORT OF THE COTTON DEPARTMENT OF THE NATIONAL AGRICULTURAL RESEARCH BUREAU IN CHINA FOR THE YEARS 1942 TO 1943, INCLUSIVE[1]

C. L. Hu[2]

THE work of the Cotton Department of the National Agricultural Research Bureau in China for the years 1942 to 1943, inclusive, was carried on in five provinces, namely, Shensi, Honan, Szechuan, Kweichow, and Yunnan. The results obtained are briefly reviewed below.

REGIONAL TEST OF AMERICAN COTTON

Regional test of American cotton were conducted in five different places in the western part of the Lung-Hai District, including portions of Honan and Shensi provinces. The results are shown in Table 1.

TABLE 1.—*Yields of seed cotton of five American varieties tested in five different places in the western part of Lung-Hai District, 1941–43.**

Locality	Variety						Remarks
	Stoneville 3	Stoneville 4	Delfes 531	Delfes 719	Lone Star 33–12	Average	
Lo-yang...	179.0	175.0	173.7	165.0	181.3	174.8	Land irrigated
Ling-poa ..	94.7	105.7	96.0	90.0	93.7	95.9	No irrigation
Dah-lih....	73.0	74.3	70.0	72.7	76.0	73.2	No irrigation
Gin-yang..	254.7	255.3	240.0	237.0	261.7	249.6	Land irrigated
Wu-kung..	194.3	202.3	174.7	188.3	194.3	190.9	Land irrigated since 1942
Average...	159.0	162.5	150.9	150.6	161.4	156.9	

*Yields expressed as catties per mow (1 catty = 1⅓ pounds, 6 mows = 1 acre).

According to the yield obtained during the past three years, conclusions may be drawn as follows: (1) Yields are much better on the irrigated lands in the western part of Lung-Hai District. (2) The yields of five tested varieties are about the same, the maximum difference in yield being less than 8%. (3) Stoneville 4, Stoneville 3, and Lone Star 33–12 yield about the same. The yields of Delfos 531 and Delfos 719 are much alike. (4) The yield of Stoneville 3 at Lo-yang, however, is a little higher than that of Stoneville 4. This result agrees with that obtained before 1937 when the Cotton Improvement Bureau of Honan Province was using Stoneville 3 for cotton extension. (5) Although Delfos 531 yields a little less than Stoneville 4 at Ling-poa, the fiber quality of the former is equivalent to that of the best Ling-poa cotton. Therefore, before the war, we could use Delfos 531 as a substitute for Ling-poa cotton while in the case of Stoneville 4

[1]Contribution from the National Agricultural Record Bureau, Chunking, China. Received for publication March 6, 1945.
[2]Head, Cotton Department.

we could not do so. (6) The yield of Lone Star 33–12 at Dah-lih and Gin-yang ranked first and is a promising variety in these two places.

COTTON BREEDING

Breeding of Delfos 531.—Pedigreed selection of Delfos 531 was conducted at Siuning, Szechuan Province. The new strains obtained since 1943 are Central Bureau Delfos 24–424 and 24–1099.

Breeding of Stoneville.—The work of pedigreed selection of Stoneville cotton has been carried on at Gin-yang, Shensi Province, since 1943. Five promising strains were obtained and the work is still in progress.

Breeding of Coker 100, Strain 2.—This work has been conducted in two places, namely, Siuning, Szechuan Province, and Gin-yang, Shensi Province. At Siuning, this variety seems to have the lowest percentage of rotten bolls. Among the American cotton varieties grown at Siuning, this variety ranked first during the past four years. Furthermore, it seems to be similar to Lone Star 33–12.

Artificial crossing of American cotton.—Several years ago, Delfos 531 was crossed with okra-leaved American cotton and one strain was selected from the progeny of this cross and was called Chicken-foot Delfos cotton. During 1943, it was compared with other standard American varieties in a variety test conducted at Gin-yang, Shensi Province. Owing to its high yielding ability (ranked first) during these two years, it has been put into increase plots to be used for extension later on. A new name, Central Bureau Chicken-foot Delfos, has been given to this new strain.

Breeding of Chinese cotton.—Pedigreed selection of Chinese cotton has been conducted at Siuning, Szechuan Province, and Si-ping, Kweichow Province. Breeding work is still in progress.

Artificial crossing work between Chinese and Indian cottons.—The work was started in 1936 at Nanking, and during 1937, 151 strains in all were brought to Siuning and selection work carried on since.

PRESERVATION OF GOOD VARIETIES AND STRAINS OF CHINESE AND AMERICAN COTTON

Since the outbreak of the Sino-Japanese war, the good varieties and strains of Chinese and American cottons of the Bureau, scattered all over the country, were brought into Free China and are still preserved by growing in specially assigned places year after year.

Preservation work at Siuning, Szechuan Province.—Up to 1943, there were altogether 200 varieties and strains of Chinese and American cottons grown in the preservation fields at Siuning. The varieties and strains deserving special mention are (1) among American cottons, Lone Star 33–12, D.P.L. 10, Foster 6, Acala 7, Missedel 4, Dixie, Early Triumph, Rowden, Coker, Cleveland, Burnett, Coker Wilds, Half and Half Pure Line, Chuchow Trice, Central University Trice, Lee-Hsien 72, and Yulling American; and (2) among Chinese cottons, Kiang-Ying White seed, Shao-kang Long Staple, Chang-Fung White seed, Chang-Fung Black seed, Chang-Teh Brown 1,

Big Boll Cotton, Ting-Hsien Cotton, Million Dollar Cotton, and Chi-Tuang Fine Staple.

A number of special selections have been made since 1942, and these, together with special selections brought from Honan and Szechuan provinces, have been grown in the preservation field at Gin-yang Station. These selections are tabulated in Table 2.

TABLE 2.—*Special selections grown in the preservation field at Gin-yang Station.*

Strain No.	Variety name	Special characteristic	Regional adaptation	Station in charge
B 29-1042	King P. L. 6306	Earliness	Northwestern provinces	Central Bureau
B 29-873*	Delfos 719	Earliness	Northwestern provinces	Central Bureau
188-1	Chicken-foot Delfos	Earliness	Yang-tze River Valley	Central Bureau
5370	Lone Star 33-12	Prolific	Yang-tze River Valley	Centeal Bureau
24-5422	Stoneville 3	Prolific		Gin-yang Station
25-289	Stoneville 4	Big Boll	Yellow River Valley	Gin-yang Station
24-543	Delfos 531	Long staple length	Yang-tze River Valley	Gin-yang Station
24-4512	Delfos 719	Long staple length	Yang-tze River Valley	Gin-yang Station
2514	Foster 6	Prolific	Yang-tze River Valley	Gin-yang Station
2851	Trice	Earliness	China, all provinces	Gin-yang Station

*Different from the original variety.

CULTURAL EXPERIMENTS

Factorial experiments on cotton topping, manuring, and ridge making have been carried on at Siuning, Szechuan Province, since 1940. The conclusions are as follows: (1) According to the environmental factors of Szechuan Province, cotton manuring has a profoundly favorable effect upon the cotton plants in Szechuan which are generally underfed. Manuring, therefore, usually promotes yield, while topping and pruning have no significant influence upon cotton yield. (2) Ridge making has not shown any significant effect upon yields. (3) Proper fertilizing and manuring may shorten the growth period of cotton, while topping and pruning have no effect upon maturity. (4) There is no interaction between topping and pruning and manuring as to yield and date of maturity.

Experiments on the date of planting were made during 1933 by the Central Bureau at Si-Ping, Kweichow Province. Trice and Si-Ping were the varieties used. According to results obtained that year, we may conclude that the best date for planting American cotton is April 20 and the best date for the planting of Chinese cotton May 5 with April 20 as a close second.

Irrigation experiments have been conducted in Shensi Province, water for irrigation being obtained from the Gin-Whai canal. The results may be summarized as follows: (1) The supply of water from the Gin-Whai canal is sufficient during the spring and fall seasons, but it is not sufficient during the months of June and July (2). Too much irrigation delays maturity, increases the amount of bad cotton, and decreases the yield. (3) There is no need of irrigation during December, February, and March and the later-half of May and August and in early September. (4) Irrigation is needed at the beginning of June, which makes it important that the annual repair of the canal should be completed before mid-May.

COTTON RESEARCH

STUDIES ON CORRELATION OF COTTON CHARACTERS

The leaf area of cotton seems to be correlated with the time of maturity and staple length. Cotton with narrow leaf lobes matures earlier but is shorter in length of staple than broad-leaf cotton, while the yields of both kinds remains the same.

The inheritance of leaf characters, such as okra-leaf, yellowish green seedling, and naked-seededness seems to be due to one pair of genes, respectively. When the two pairs of genes were combined in a cross, the progeny showed the phenomena of independent segregation. The homogeneous purple leaf character seems to be correlated with low yield, while its heterogeneous form seems to be correlated with short staple length. Okra-leaf cotton usually has a higher rate of boll shedding, and the fiber is shorter also. Cotton grown up from the yellowish green seeding usually has shorter staple, higher lint percentage, and a lesser number of five-locked bolls.

ANALYSIS OF FACTORS PERTAINING TO YIELD

The factors directly responsible for the yield of lint cotton are number of bolls, percentage of lint, percentage of rotten locks, and size of the boll. Among these four factors the number of bolls matured is negatively correlated with the percentage of rotten locks.

The correlation between number of picked bolls and yield of lint cotton is still very significant, although the effect of other factors has been eliminated in partial correlation. The degree of negative correlation between rotten locks and cotton yield will be lowered after the elimination of the effect of picked bolls, while the degree of positive correlation between weight per lock and yield will be increased after eliminating the effect of rotten locks.

The factors influencing the number of picked bolls are the total number of flowers opened, the number of flowers opened by the end

of July, and the percentage of boll shedding after flowering. The number of flowers opened by the end of July is negatively correlated with the number of rotten bolls, while the total number of flowers opened, the percentage of shedding after flowering, and the number of picked bolls show a positive correlation. This correlation, however, proves to be negative after eliminating the effect of the total number of flowers opened.

The factors influencing the number of rotten locks are the date of flowering and the days of growth of the green boll; therefore, early cotton usually has the lesser number of rotten locks.

Factors positively correlated with the percentage of lint are lint index, seed index, and the weight of 100 seeds of seed cotton. The correlation between seed index and lint index is rather high. The correlation between lint percentage and seed index shows a negative trend after eliminating the effect of lint index.

The correlations between weight per lock and lint index, seed index, weight of 100 seeds of seed cotton, and lint percentage are all positive.

The correlation between yield and earliness is very high, while the latter is again correlated with the percentage of picking before September 20, the percentage of bolls by the end of July, the number of flowers opened by the end of July, and the number of cotton or fruiting branches.

GROWTH STUDIES IN COTTON

Growth studies of eight varieties of Chinese cotton and 10 varieties of American cotton have been carried on at Siuning for three years. The results may be briefly summarized as follows: (1) American cotton grows faster during the early period of growth, while Chinese cotton grows faster at the later period. (2) American cotton has a larger number of flowers per plant than Chinese cotton, although the former has the higher rate of boll shedding. (3) Flowers opened at an early date usually have a greater possibility of maturing bolls than those opened at a later date. (4) The number of flowers opened is highly correlated with the temperature 20 to 30 days before flower opening, but there is no correlation between the number of flowers opened and the temperature on the day the flower opens. (5) The curves of maximum boll opening and of maximum flowering usually coincide with each other should the flowering curve be superimposed on the boll opening curve. (6) The average number of days required to mature Chinese cotton bolls is from 35 to 42, while that required for American cotton boll is 40 to 46. (7) The percentage of rotten bolls is positively correlated with the days of boll maturity, and, as a result, American cotton usually has a much greater number of rotten bolls than Chinese cotton.

STUDIES ON THE HEREDITY OF COTTON

The hereditary behavior of anthocyanin in Chinese cotton has been studied for several years. Formerly, 14 pairs of genes were found. By 1932, another four pairs of genes were added to the list. There are (1) The gene for green stem and light red petal spot; (2) the gene for light purple stem, red margined corrola, light red petal spot;

(3) the gene for light purple stem, red margined corrola, red petal spot; and (4) the gene for light purple stem, red margined corrola, and absence of red petal spot.

In American cotton there are found three types of yellowish green seedlings and two types of leaf forms, these hereditary characters are tabulated as shown in Table 3.

TABLE 3.—*Linkage relations of some inherited characters in American cotton.**

Newly found characters	Other characters						
	Yellowish green leaf (a)	Red stem	Chicken-foot leaf	Brown lint	Green lint	Naked seed	Green seed
Light yellowish green seedling.	O	O	O	O		O	
White apical bud. . . .		O	O	O		O	
Irregular leaf vein. . .					L		L
Wave like margined leaf.		O	O	O			O
Yellowish green seedling (a).		O	O	O			O

*L = Linkage; O = Independent segregation; Blank = Not yet studied.

Hybrid plants of Chinese and American cotton were backcrossed to American cotton and Chinese cotton, respectively. Those back-crossed to American cotton have progeny resembling American cotton, while those back-crossed to Chinese cotton have progeny generally similar to Chinese cotton with the exception of stem color and branching habit.

EXPERIMENTS WITH TREE COTTON

The Bureau has conducted research work on tree cottons of Yunnan Province since 1938. Pedigreed selection of tree cotton has been carried on at Kai-Yuan, Yunnan Province. The variety used was the native free-seeded tree cotton. At present, there are 21 strains on trial. In 1943, the average of seed cotton per mow for these strains was 170 catties and the average length of staple 30 mm.

A number of varieties of tree cotton have been collected from various placed in Yunnan Province. The varieties include Yin-sun, Tsa-li, Mee-leh, Ma-kiang, and several others. These were grown with Sea Island, Pima, Ciga, Tanguis, and Seabrook, and the varietal characteristics have been noted from time to time.

TEN YEARS' RESULTS OF EXPERIMENTS AND EXTENSION WORK WITH DELFOS COTTON IN CHINA[1]

C. L. HU[2]

THE regional test of cotton varieties carried out in 1933 by the National Agricultural Research Bureau proved that Delfos 531 was a promising variety in the Yangtze River region. In 1933, this variety was introduced from the United States and was propagated in several localities. In 1937 it was distributed to the farmers. Since then, it has become one of the leading varieties of cotton in China. This paper summarizes the results of experiments and extension of this cotton variety carried out during the past 10 years.

During a period from 1933 to 1935, regional tests were carried on in different localities. According to the results obtained, Delfos 531 yielded higher than any other variety included in the Yangtze River region, especially in Nanking and Anching. The average of 9 to 10 tests in that region showed that this variety gave an increase in yield of 15.77% in 1934 and 7.72% in 1935 over the check varieties, chiefly Trice and Acala. In the Yellow River region, Delfos 531 gave increases in average yield over the check variety (Trice) of 31.6% and 32.37% for 1934 and 1935, respectively. Another introduced variety, Stoneville, yielded even higher. Thus, the wide range of adaptation of this variety was well proved.

Besides its high yield, Delfos 531 also has the best quality in comparison with the varieties commonly grown in China. It has longer fiber than Trice, Acala, or Stoneville, and its average lint percentage is higher than Trice but slightly lower than that of Stoneville and Acala. Table 1 gives a comparison of Delfos 531 and three other introduced American varieties with respect to fiber length and lint percentage.

TABLE 1.—*Comparison of American cotton varieties.*

Character	Year	Trice	Stoneville 4	Acala	Delfos 531
Length of fiber, mm	1934	25.60	29.20	30.20	32.60
	1935	26.51	29.21	28.82	32.44
Average.........		26.05	29.21	29.51	32.52
Lint percentage.....	1934	28.60	31.60	30.40	29.40
	1935	30.15	31.83	33.11	31.23
Average.........		29.37	31.76	31.75	30.50

After the outbreak of the war, the adaptation of this variety was tested in the southwestern provinces, especially Szechuan. In several localities in Szechuan and Sikang provinces its yield was superior or at least equal to the recently developed American varie-

[1]Contribution from the National Agricultural Research Bureau, Chungking, China. Received for publication March 6, 1945.

[2]Head, Cotton Department.

ties, such as Foster 6 and Cokers 100, and the local degenerated American varieties. Trice, which was previously recommended to the growers of that region, exceed Delfos in a few tests in yield. However, so far as quality, lint percentage, and other economic characters were concerned, Delfos 531 was definitely preferable.

In 1935, Delfos was purchased from the Stoneville Pedigreed Seed Co., and its propagation was begun in Nanking in an area of 180 mows.[3] Since 1937, it was extensively used in extension work. The one-variety-community system was adapted and the growing region was gradually extended from a number of extension centers.

The Honan Provincial Cotton Improvement Station first introduced this variety to the cotton growers to take the place of the degenerated but much famed American variety Linpao. An area of 8,154 mows near Shanchow were selected to grow this variety exclusively to maintain its purity. The high yield and good quality of Delfos received much admiration from the growers. In 1937, the Sino-Japanese war changed much of the agricultural policy of our government so as to pay more attention to increased food production, but the extension work on cotton in Honan Province was kept going in spite of war. Areas of 33,400, 31,288, 27,322, 24,058, and 25,509 mows of Delfos cotton were growing in that region in the years from 1938 to 1942, respectively. These figures included only the acreage under the control of the Station, but a much larger area was devoted to the growing of this variety through the purchase and exchange of seeds among individual growers.

After the war began most of the cotton growing regions were occupied by the Japanese, hence Szechuan Province has had to increase its cotton production. However, owing to the lack of precise experimental data for reference, it was difficult to decide which variety should be introduced to this region. After a thorough consideration of the climate and cultural conditions, it was determined to use Delfos 531. In 1938, 100,000 catties[4] of seed of that variety were imported from Honan Province and distributed to the growers in the northern part of Szechuan Province, chiefly Shehung. Throughout the growing season close attention was paid to the plant growth and behavior of the variety. Various defects in the cultural and harvest practices were noticed and suggestions as to their improvement were made. Eventually the local growers were definitely convinced by its high yield and good quality and the adaptation of this variety to northern Szechuan Province was determined.

During the winter of the same year, 500,000 more catties of clean seeds of Delfos 531 and Delfos 719 were imported under a very difficult situation. An area covering Shehung, Santai, Chungkiang, Pungchi, and Shuning was selected to grow this cotton on the basis of the one-variety-community system. In 1939, this variety of cotton was grown on 56,312 mows. The low precipitation in the fall made that year a very favorable one for the growing of cotton. The highest yield of seed cotton of Delfos reached 330 catties per mow and an average of 176 catties per mow was recorded in comparison with 105

[3] 6 mows = 1 acre.
[4] 1 cattie = 1⅓ pounds.

catties for a degenerated American variety and 137 catties for the variety Trice.

In 1940, the extension area for Delfos extended to 14 districts, located chiefly in northern Szechuan Province and the Too River region. The total area was 113,457 mows. The drought and a storm in the early summer of that year did not cause much damage to its growth and the superiority of this variety was still retained.

In 1941, the sudden increase in the price of food crops caused a decrease in cotton planting. Therefore, the total area in Delfos in 1941 was only 158,200 mows. In 1942, the same reason caused the reduction in the area of Delfos cotton to 104,131 mows. During this period, however, various attempts were made to keep its purity and to avoid the degeneration of this variety by the strict control of the growing area and gin-houses in order to supply a large quantity of pure and clean seeds for latter extension work.

TABLE 2.—*Results of extension work with Delfos cotton in China.*

Year	Area in mows*	Average yield of seed cotton per mow, catties†	Increase in yield over local varieties per mow, catties
1939	56,312	176.0	61.0
1940	113,457	115.1	50.1
1941	158,200	150.3	71.0
1942	164,131	139.0	81.0

*6 mows = 1 acre.
†1 cattie = 1⅓ pounds.

The results of extension work on Delfos during the period from 1939 to 1942 are summarized in Table 2.

A PLAN FOR REHABILITATION OF THE COTTON INDUSTRY IN CHINA DURING THE POST-WAR PERIOD[1]

C. L. Hu[2]

CHINA is the biggest consumer of raw cotton, yarn, and cloth in the world. Although it ranks third in the production of cotton, the import of cotton goods ordinarily exceeds export at a value of about three hundred million dollars in Chinese currency each year (one hundred million dollars in American currency).

The population of China is about one-fifth of the world, but the amount of cotton produced in China is only about one-twelfth to one-eighth of the world crop. Besides making cloth, a large quantity of cotton is required for batting, wadding, and stuffing materials. Our own production is far from enough to supply such demands. During the period from 1932 to 1937 the area devoted to cotton in China was 9,000,000 acres, producing yearly 1,820,000,000 pounds of cotton. In 1936 we had the largest acreage of cotton ever recorded in China, or approximately 10,000,000 acres with the production of 1,871,000,000 pounds of cotton. Besides the consumption of cotton produced by our own acreage the average import of raw cotton during the period from 1921 to 1936 amounted to 227,000,000 pounds annually. The total quantity required for our yearly consumption was 2,050,000,000 pounds on an average, which included 1,289,000,000 pounds for machine spinning, 230,000,000 pounds for hand spinning, and 577,000,000 pounds for stuffing materials.

In 1937 we had 141 cotton mills, operating 5 million spindles. This means the output of one spindle had to be shared by 100 men. Each year there was produced by our mills 1,088,000,000 pounds of yarn and thread. In addition to this about 220,000,000 pounds were produced yearly by hand spinning. In total, the amount of yarn thus produced yearly would be estimated at 1,323,000,000 pounds. During the period from 1917 to 1920, the yearly import exceeded the export by 5,600,000 pounds. The total consumption of yarn amounted to 1,276,000,000 pounds for each year, including 415,000,000 pounds for loom weaving, 690,000,000 pounds for hand weaving, and 160,000,000 pounds for needle work.

When the production of cloth is taken into consideration there were 52,009 looms in China in 1937, producing 1,000,000,000 square yards of cloth. In addition, 2,329,000,000 square yards were produced by hand weaving, making a total of 3,329,000,000 square yards produced yearly. The total yearly consumption was estimated to be 3,800,000,000 square yards. On an average, therefore, during the period from 1911 to 1936, we had to import yearly 483,000,000

[1]Contribution from the National Research Bureau of China. Received for publication March 6, 1945.

[2]Head, Cotton Department. Dr. Hu was sent by the Chinese Government to join the work with United Nation Relief and Rehabilitation Administration and to study cotton production in the United States. His stay in the United States will be approximately one year.

square yards of cloth in order to compensate for the deficiency in production.

In conclusion, before 1937, our import of yarn far exceeded the amount exported; therefore, production of raw cotton and especially of cloth was far from self-sufficient and consequently we had to depend upon the importing of a large quantity to meet the total consumption.

THE PRESENT SITUATION

Since the outbreak of the Sino-Japanese war in 1937, the production of cotton, spindles, and looms had been seriously curtailed. The figures of loss are as follows:

A. The cotton growing area which remained in Free China was only about 14% of the total. This fact naturally leads to an extreme deficiency in the supply of cotton.

B. Before the war, our cotton mills were mostly located along the coast. Since the outbreak of the war, 97% of the spindles still remained there. Even through the efforts of our government to establish the industry in the interior, there are only 200,000 spindles in Free China.

C. During the early part of the war, nearly all of the looms were seized by the Japanese. There exist now only 1,000 looms scattered over the interior.

In view of the above facts, the damage from the war has resulted in the overthrow of nearly the whole cotton industry. Consequently, the insufficiency in the supply or raw cotton, yarn, and cloth can be easily imagined.

PLAN OF REHABILITATION OF COTTON INDUSTRY

COTTON MILLS

Before the war, because of the increasing demand of fine yarn, hand spinning was already gradually declining. After the war, the deficiency of man labor will probably prohibit the recovery of the hand industry. In order to make the cotton supply self-sufficient, we must build up 10 million spindles within 10 years. For such work we shall need assistance from our allies; all will be planned by our engineers. In addition to the above our original 5 million spindles that have been seized by the Japanese must be returned to us in good condition. Before these old spindles are regained and the new industry is founded, i.e., the first year after the war, we trust our allies will be in a position to supply us with 154,000,000 pounds of yarns to meet the immediate demands.

LOOMS

During the postwar period we plan to build 320,000 looms in addition to our lost 50,000 looms that should be returned to us in good condition. In the first year after the victory, we shall need the help of our allies in supplying 200,000,000 square yards of cloth to solve the urgent problem of clothing.

COTTON PRODUCTION

After the war, we plan to plant 12,000,000 acres to cotton in order to produce 3,307,000,000 pounds of raw cotton annually.

The chief process in rehabilitating the cotton industry in our country during the postwar period is to increase the yield per unit area; hence, the introduction of good varieties is of great importance. According to the results of our "Regional Tests", we are sure that Stoneville 4 (now called Ambassador 4, bred by the Stoneville Pedigreed Seed Co., Stoneville, Miss)., is well adapted in the Yellow River Valley, covering the Provinces of Hopeh, Honan, Shangtung, Shansi, Shensi, Anhuei, and the Huai River Plain in north Kiangsu. Delfos 531 is adapted to the provinces along the Yangtze River, including Kiangsu, Anhuei, Hupeh, and Szechuan. In the experiments undertaken in the Yellow River region, Stoneville 4 yielded an average of 73 pounds of lint cotton per acre more than other varieties, and in the Yangtze River region Delfos 531 yielded an average of 86 pounds more per acre. These two varieties will be best suited for the rehabilitation of our cotton production when the war is over. One other variety that should be mentioned is Trice which possesses adaptability over a wide range. Where Stoneville 4 and Delfos 531 do not grow well, Trice can be used as a substitute for the native varieties.

During the war we have grown 154,000 acres of Stoneville 4 in Shensi Province, 46,000 acres of Delfos 531 in Szechuan Province, and a small quantity of Trice. Our plan for the future is to provide sufficient seeds of these three varieties for planting the first year after the war for all of the war-torn cotton fields. Seed of these varieties should greatly increase the yield per acre.

In 1937, in the region along the Yellow River, there were 5,600,000 acres of cotton. The first year the war we plan to raise 3,000,000 acres of Stoneville cotton in this region. With us it takes 52 pounds of seed per acre. We trust that besides our own production, the United States will supply us with 50,000 tons of Stoneville cotton seed.

There were 4,400,000 acres of cotton in the Yangtze River region in 1937. After the war, we intend to grow 1,500,000 acres of Delfos cotton in that area, and in the first year we should have enough seed for 500,000 acres. As one acre requires 78 pounds of seed of this variety, we shall need 10,000 tons of Delfos cotton seed from the United States.

In our crude process of extraction of cotton oil, the fuzz is usually not removed, and therefore is wasted. We plan to establish 50 cotton oil mills in the various cotton-growing regions, and we wish to obtain 50 whole sets of machines consisting of sand-and-boll screen, delinting machine, cotton seed huller, cotton seed rolls, cooker, former, hydraulic press, refining equipment, etc., from our allies.

YIELD-DEPRESSION EFFECT OF FERTILIZERS AND ITS MEASUREMENT: III. AGROBIOLOGICAL ANALYSIS OF CERTAIN MULTIPLE-FACTOR FIELD TESTS SHOWING DEPRESSION BY NITROGEN[1]

O. W. WILLCOX[2]

THE principal material for this paper was obtained from a nitrogen, phosphorus, and potassium experiment with potatoes on an acid Sassafras sandy loam located on the Eastern Shore of Virginia in 1943, as reported by R. L Carolus.[3] The fertilizer treatment (per acre) embraced all possible combinations of 60, 120, and 180 pounds of N; 80, 160, and 240 pounds of P_2O_5; 60, 120, and 180 pounds of K_2O; and 0 and 120 pounds of CaO in the form of gypsum. Each treatment was in triplicate, giving 18 series comprising a total of 54 treatments and 162 plots. The calcium in the form of gypsum was not observed to have any material effect on the yields.

Inspection of the data reported by Carolus shows that, in every series, amounts of nitrogen in excess of 60 pounds significantly reduced the yield of tubers. On the other hand, while the yield-lowering effect of increasing amounts of nitrogen pervades the whole work, it is evident that increased amounts of phosphorus and potash have acted to counteract the overall depressive effect of nitrogen; or, stated differently, we have before us the case where added nitrogen is out of nutritional balance with other growth factors concurrently present, and where the unbalance is at least partially corrected by increased additions of two other nutrients, namely, phosphorus and potash. Our object here is to make an agrobiologic analysis of this field test to the extent warranted or suggested by the published data.

Quantitative agrobiology is based primarily on Mitscherlich's law of the effect factors of the factors of plant growth, as expressed by the Mitscherlich-Baule normal yield equation $y=A(1-10^{-0.3 \cdot .01x})$, which describes the action of any factor of plant growth, e.g., nitrogen, when this factor is acting positively to promote the growth of plants. It has also been shown that when this same factor is supplied to the crop on an otherwise normal soil in amounts that are out of due proportion with other plant nutrients, it acts negatively to depress plant growth. In that case the *whole* action of the growth factor is described by Mitscherlich's depression equation $y=A(1-10^{-0.301x}) \cdot 10^{-kx^2}$, where the coefficient k measures the depressive effect.

In approaching this case it will be helpful to have in mind the general configuration of the Mitscherlich yield-depression diagram, which shows a family of curves calculated for different values of k, as in Fig. 1. On this diagram (here abridged) it will be noted that each depression curve branches off from the normal curve and at first continues to rise with an outwardly convex profile to a certain

[1]Received for publication February 5, 1945. Previous papers in this series will be found in this JOURNAL, 36:20–29, 1944; 37:9–20, 1945.

[2]Consulting Agrobiologist, 197 Union St., Ridgewood, N. J.

[3]CAROLUS, R. L. Influence of nitrogen, phosphorus, potash, and calcium on tuber and foliage weight of potatoes. Amer. Potato Jour., 21, No. 7:199–203, 1944.

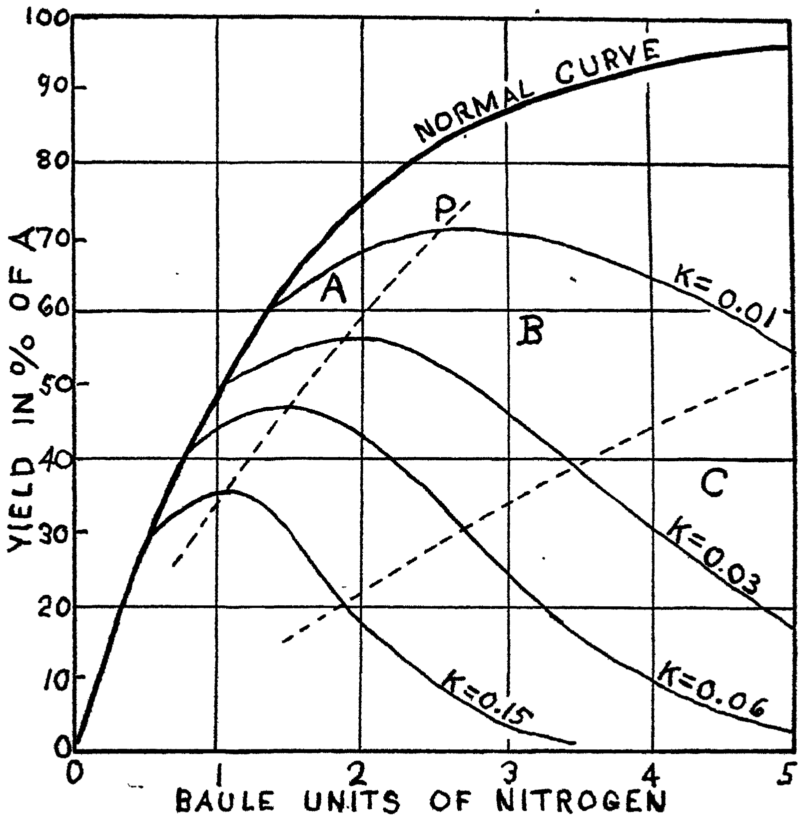

FIG. 1.—Standard yield-depression diagram (abridged).

maximum, or peak, P. After passing the peak the curve, still outwardly convex, turns down. Farther on it reverses its curvature and then presents a concave profile. By drawing a broken line through the peaks and another through the points where the curvature reverses, we divide the field of the diagram into three regions which, for convenience of discussion, we designate as A, the region of positive convexity where the yield still increases; B, the region of negative convexity where the yield decreases; and C, the region of concavity where the curves asymptotically approach the line of zero yield.

To facilitate the agrobiologic diagramming and discussion of this field test it is well to regroup the data of Carolus, as shown in Table 1. This table presents the whole work in three sections, each section displaying the effect of one of the three principal factors in 18 series, including treatments with and without CaO in the form of gypsum, wherein this factor was varied against a fixed base fertilization composed of the other two factors. We are thus enabled to draw 18 yield curves showing the effects of graded increments of a given factor under 18 different conditions that were kept constant in a particular series.

TABLE 1.—*Effect of N, P, K, and CaO on potato yields (Carolus).*

The Nitrogen Factor

Base fertilization, lbs. per acre		Yields, bags per acre							
		Series No.	N, lbs. per acre, without CaO			Series No.	N, lbs. per acre, with CaO		
P_2O_5	K_2O		60	120	180		60	120	180
80	60	I	111	98	90	X	109	106	95
80	120	II	114	99	91	XI	115	105	91
80	180	III	106	104	87	XII	112	105	90
160	60	IV	119	111	107	XIII	117	113	99
160	120	V	123	117	103	XIV	128	112	98
160	180	VI	134	118	106	XV	128	120	117
240	60	VII	126	122	102	XVI	125	119	110
240	120	VIII	135	121	105	XVII	128	120	109
240	180	IX	127	134	112	XVIII	135	131	123

Phosphoric Acid Factor

N, lbs. per acre	P_2O_5, lbs. per acre	Series No.	P_2O_5, lbs. per acre			Series No.	P_2O_5, lbs. per acre		
			80	160	240		80	160	240
60	60	I	111	119	126	X	109	117	125
60	120	II	114	123	135	XI	115	128	128
60	180	III	106	134	127	XII	112	128	135
129	60	IV	98	111	122	XIII	106	113	119
120	120	V	99	117	121	XIV	105	112	120
120	180	VI	104	118	134	XV	105	120	131
180	60	VII	90	107	102	XVI	95	99	110
180	120	VIII	91	103	105	XVII	91	98	109
180	180	IX	87	106	112	XVIII	98	117	123

Potash Factor

N lbs. per acre	P_2O_5, lbs. per acre	Series No.	K_2O, lbs. per acre			Series No.	K_2O, lbs. per acre		
			60	120	180		60	120	180
60	80	I	111	114	106	X	109	115	112
60	160	II	119	123	134	XI	117	128	128
60	240	III	126	135	127	XII	125	128	135
120	80	IV	98	99	104	XIII	106	105	105
120	160	V	111	117	118	XIV	113	112	120
120	240	VI	122	121	134	XV	119	120	131
180	80	VII	90	91	87	XVI	95	91	98
180	160	VIII	107	103	106	XVII	99	98	117
180	240	IX	102	105	112	XVIII	110	109	123

TABLE 1.—*Concluded.*

General Averages					
Nitrogen treatments		Phosphate treatments		Potash treatments	
N, lbs. per acre	Yield, bags per acre	P_2O_5, lbs. per acre	Yield, bags per acre	K_2O, lbs. per acre	Yield, bags per acre
60	122	80	102	60	109
120	114	160	115	120	112
180	102	240	121	180	116

We first plot the yields of tubers in the 18 nitrogen series against the three treatments with this factor: 60, 120, and 180 pounds per acre. Since some of the curves that may be drawn from these data overlap and some of the individual yield points are obviously erratic, it would be confusing to show them all on one diagram. We therefore select five from the larger number that appear fairly representative. The data of the five selected series, which cover the range of addi-

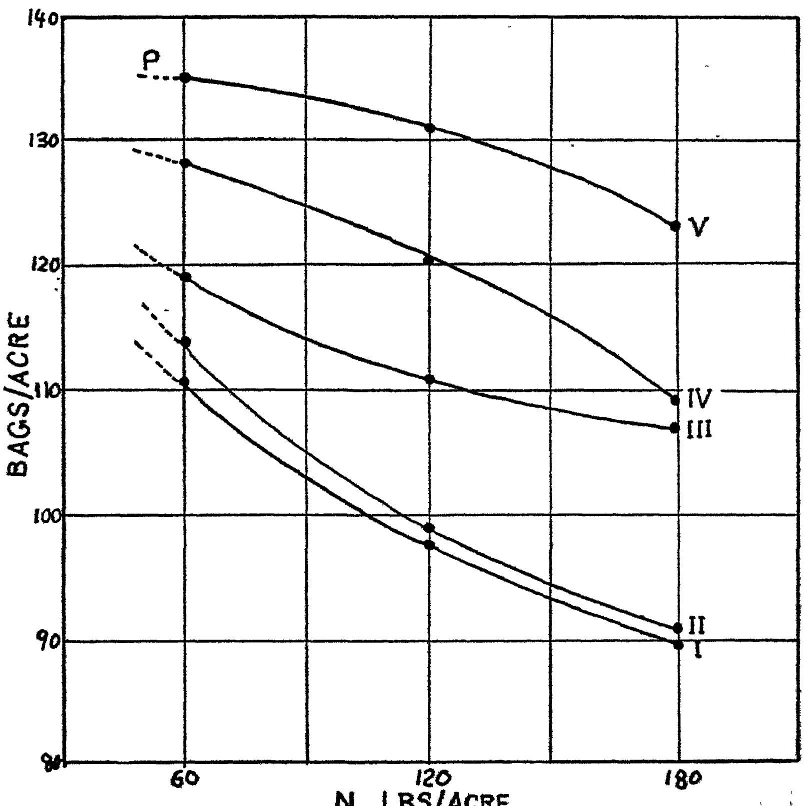

FIG. 2.—Curves showing yield depression by N in a NPK field experiment with potatoes.

TABLE 2.—*Numerical data of the curves shown in Fig. 2.*

Series No.	Fertilizer applied, lbs. per acre			Yield of tubers, bags per acre
	N	P_2O_5	K_2O	
I	60	80	60	111
	120	80	60	98
	180	80	60	90
II	60	80	120	114
	120	80	120	99
	180	80	120	91
III	60	160	60	119
	120	160	60	113
	180	160	60	107
IV	60	240	120	125
	120	240	120	121
	160	240	120	107
V	60	240	180	135
	120	240	180	131
	180	240	180	123

tions of phosphate and potash from the smallest to the largest are shown in Table 2 and in Fig. 2.

While the depressive action of increased nitrogen is plainly evident in every series, it is equally plain that increased amounts of potash and phosphate have raised the overall yields, i.e., the curves lie progressively higher in the diagram. Of course, anyone could tell as much merely by looking at Table 2, but what chiefly engages our interest are the configurations of these curves. The family resemblance between the curves of Figs. 1 and 2 easily attracts attention, even though the curves of Fig. 2 are only segments of the whole curves that might be drawn if we had more experimentally determined points. Thus, curves I and II are frankly concave, with their left-hand ends pointing steeply upward. They are obviously segments of depression curves that have extended beyond the point of curvature reversal, and therefore they belong in region C (compare the two lower curves in Fig. 1, for which the values of k are 0.15 and 0.06). Curve I, which is the most depressed, corresponds with the lowest additions of phosphorus (80 pounds) and of potash (60 pounds); curve II lies somewhat higher, evidently due to the presence of 120 instead of 60 pounds of potash. On the other hand, curves IV and V are negatively convex and hence must lie in region B (compare the two upper curves in Fig. 1 where the k values are 0.03 and 0.01). Curves IV and V correspond with the largest additions of phosphorus and potash. Curve III occupies an intermediate position; its concave profile is much flattened.

The corrective influence of phosphorus and potash on the depressive action of nitrogen in these series of experiments may be agrobiologically summarized thus: With progressive increase in the

amounts of added phosphate and potash, the magnitude of the depression factor k involving nitrogen is progressively reduced. The visible result of this decrease of k is that not only are the experimental curves lifted higher in the diagram, but also they are eventually moved out of region C into region B. It is to be noted, however, that the action of phosphate and potash has stopped short of lifting the yield points to the position of a normal curve and has not even produced a yield curve lying partly in region A, though the left-hand end of curve V seems to lie near its peak. The corrective effect of potash on yield-depression by nitrogen has been exemplified in a previous paper (this JOURNAL, vol. 37, page 18).

From the general facies of Fig. 2 we can draw some conclusions that appear fairly safe. One is that this field was heavily supplied with nitrogen before the experiment was begun. We get an inkling of this situation from the account given by Carolus of the antecedents of the 1943 experiment, which was preceded by similar experiments in 1942 and 1941. The yields in those years were extremely poor, due to dry seasons, which, according to Carolus, must have resulted in an accumulation of residual nitrogen. In the summer and fall of 1942 the field was green-manured with sorghum which, favored by the rains, made an extremely heavy growth that undoubtedly prevented the leaching of this nitrogen, and when plowed under in November must have produced a large volume of nitrifiable organic substance.

We can use an indirect method of obtaining a presumptive idea of the amount of this accumulated nitrogen. As noted above, all the curves of Fig. 2 are frankly depression curves. The three lower curves, I, II, and III, being concave, must lie far to the right of their theoretical peaks, although the data give us no means of exactly locating these peaks. However, we may follow a clew which seems to be afforded by curve V, the least depressed of the five. It will be observed that at its left-hand end curve V is nearly horizontal, suggesting that it begins at or near its theoretical peak. Also, to judge from its general appearance, curve V is a segment of a curve that would about coincide with the equivalent of a curve like the upper one in Fig. 1. To verify these assumptions we would have to make an experimental determination of the normal, undepressed nitrogen curve on this field. Assuming, then, that curve V is about the equivalent of the upper curve in Fig. 1, and that its front end lies at the peak, we drop a perpendicular from P (Fig. 1) and observe that this perpendicular cuts the horizontal axis at a point corresponding to 2.5 baules, which we may regard as measuring the average amount of soil nitrogen in this potato field after the first addition of 60 pounds. The next higher addition brought this amount to 2.77 and the third to 3.04 baules of nitrogen.

Of itself, 3 baules of soil nitrogen (669 pounds) is not an excessive amount, being that quantity that is required to produce 87.5% of any maximum crop A. To produce around 96% requires 6 baules. An immediate question arises in the present case as to whether 2.5 to 3 baules of N are relatively excessive as regards the amounts of

phosphate and potash originally present plus what was added for the experiment. This question is of importance because yield depression on this field is associated with the nitrogen factor and an excess of nitrogen over the other factors has often been noted to cause depression. Excesses of phosphate and potash over nitrogen are usually much less depressive.

The data recorded by Carolus enable us to measure the average amounts of soil phosphorus and potash that come into consideration. In contrast with nitrogen, which has acted negatively to keep down the yields, both phosphate and potash have acted positively to increase them. We see this from the fact that the higher increments of these factors have generally produced larger yields than the lower ones, and when these yields are plotted we get rising instead of falling curves. For example, a random selection of graphs of five of the individual potash series is presented in Fig. 3. Although these five curves have a generally upward slope we observe considerable scattering of the yields, which are distributed haphazardly above and below or on their median curves, and the indicated A values differ considerably. Hence, none of these curves, taken singly, can be accepted as representative of the whole field. However, when we take the general average of all 18 series of the potash section, we get a diagram (lower right corner of Fig. 3) where the yield points lie quite close (maximum deviation less than 2%) to curve $A = 120$ as their median. Noting the position of the first yield point of this curve above the horizontal axis, we find that this point corresponds to 3.2 baules of potash, while the highest yield point corresponds to 4.51

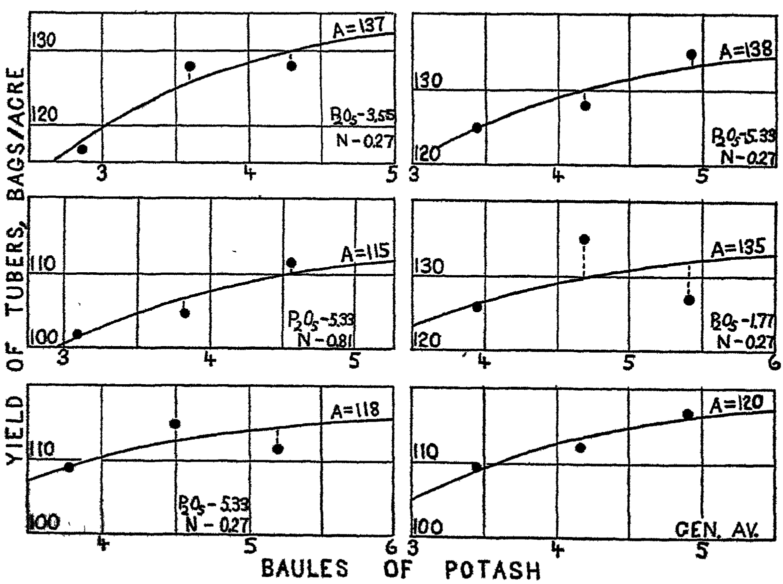

FIG. 3.—Curves of five individual series and the general average of the yield-increasing effect of potash in Carolus' NPK experiment.

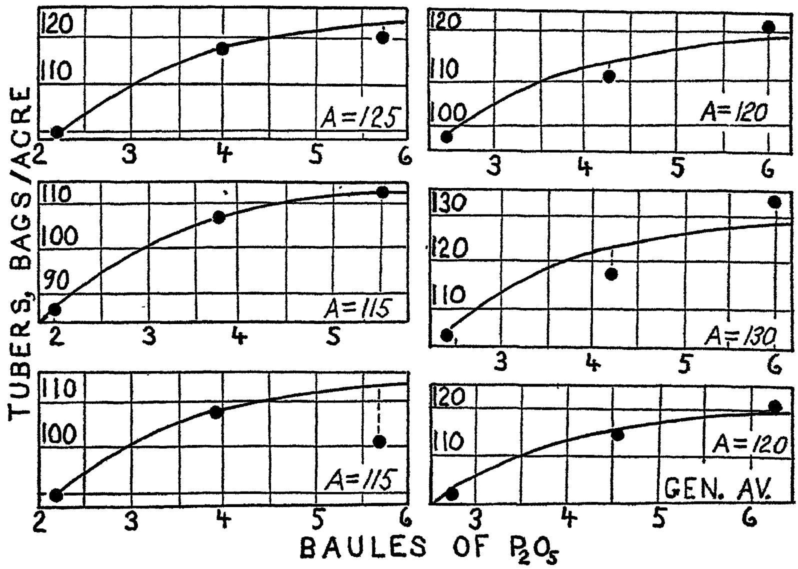

FIG. 4.—Curves of five individual series and the general average of the yield-increasing effect of phosphate in Carolus' NPK experiment.

baules. Therefore, the average amount of potash in action in this experiment was not less than the amount of nitrogen.

A similar situation exists in the phosphoric acid section of the experiment. Fig. 4 presents a random selection of five of the individual phosphate series. The haphazard distribution of the yield points and the variability of the A values are again in evidence, and it is again left to the general average of all 18 of the phosphate series to show a normal fit of satisfying closeness on curve $A = 120$. Thus, the averages of both the phosphate and the potash sections settle down on the same normal curve, which defines their maximum yield-producing potential under the average conditions of this test. The agrobiologic significance of this apparent coincidence will be pointed out below. In the mean time it will be noted that after the addition of the first increment of phosphate the soil contained 2.5 baules of P_2O_5 and after the highest addition 6.15 baules. Therefore, the average amount of phosphate in action was not less than the average amount of nitrogen.

We thus appear obliged to conclude that the yield-depressing effect of nitrogen in this test was not due to a preponderance of nitrogen over phosphate or potash, and there is nothing elsewhere in the record on which to fix responsibility for the condition of unbalance. It is very certain that the depressive action of nitrogen was markedly counteracted by the additions of phosphate and potash, but, as previously remarked, the quantities of these factors used fell short of converting the nitrogen depression curve into a normal one, and the question might arise of whether normality of nitrogen ni-

trition could have been attained by using still larger amounts of phosphorus and potash. However, a reference to the general average diagrams of Figs. 3 and 4 seems to preclude this. Thus, the diagram of the average for phosphorus shows a final content of 6.15 baules of this factor in the soil, which is sufficient for above 96% of any maximum crop. The potash average curve shows a final potash content of 4.55 baules, sufficient for a 95% yield. There is not much margin for further increase in either case. It is perhaps possible that the depression was due to an involvement of nitrogen with some other deficient factor, which might be one or another of the minor nutrients, or it might be the low soil pH, but the circumstances so far as disclosed in the record give little room for speculation. At any rate, the phosphate and potash treatments failed to normalize the nitrogen nutrition, leaving what is presumed to be a wide gap to be closed by discovery of the responsible factor. The largest yield obtained by Carolus in this test was 135 bags (225 bushels) which has to be regarded as moderate in comparison with the known "quantity of life" of the potato agrotype.

DISCUSSION

The law of the effect factors of the factors of plant growth was announced by Mitscherlich in 1909. This fundamental principle of agrobiology says that "within every factor of plant growth there resides a perfectly definite effect factor that is independent of other cultural conditions and is independent of the nature of the plant itself". It is now 36 years since this principle became known and there are still some agronomists and plant physiologists to whom it is meaningless. This is perhaps because of their lack of familiarity with the accumulated evidence, not to mention the evidence which many of them could perhaps find buried in their own undigested experimental data. At this late date it is hardly necessary to make new experiments to obtain proof of the validity of the Mitscherlich law. The proof may be found in every field test that has been adequately replicated and competently executed, and the work of Carolus is an example in support of that statement.

This work may be examined first for proof that the effect factor of a growth factor is independent of other cultural conditions. Whatever may have been the cause of the depressive action of nitrogen in this experiment, it did not act to prevent either phosphate or potash from fulfilling their roles as factors of plant growth according to the normal law of crop increase as expressed in the normal yield equation $y = A(1-10^{-0.301x})$. Looking at the general average curves shown in Figs. 3 and 4, we see that the effect of potash has closely followed the curve of the equation $y = 120(1-10^{-0.301x})$ and that the effect of phosphate as closely follows the same curve. Thus, both these factors conform to the effect law regardless of the special circumstances (possibly of a physiologic or toxic order) that have affected the nitrogen factor. Throughout the experiment the depressive action of nitrogen was opposing the yield-producing energy of phosphate and potash and limited the average *A* values of these factors to 120 bags; but within the limits permitted by the existing

physiologically hostile condition, the phosphate and the potash obeyed the law.

Many agronomists and plant physiologists find special difficulty in accepting the principle, derived from the effect law, that all plant species require the same concentrations of a given factor of plant growth to produce the same percentages of their respective maximum crops. The inverse of this proposition is that the same quantity of a named growth factor will produce the same percentage of the maximum yield of any plant, which amounts to saying that 1 Baule unit of any factor has the same yield-producing potential as 1 baule of another factor. This principle runs counter to much experimental evidence that seems to show that some crops have different requirements for different nutrients. The writer has examined much of this contradicting evidence and has found none that is exempt from criticism, but without going farther into that let us see what the work of Carolus has to show.

Referring again to the curves of the general averages for potash and phosphate in Figs. 3 and 4, the potential *A* value of each of these factors is 120 bags, and both approach this *A* value along the same curve. If the two curves are drawn to the same scale and superposed one on the other, it is seen that 1 baule of added potash increased the yield as much as 1 baule of added phosphate. The fact that in this well-replicated test both general averages settle down on the same normal yield curve is no mere coincidence; it is the result of both factors obeying the same agrobiologic law. In this experiment there was only one test plant; how the rule works in tests with two different agrotypes will be shown in connection with Fig. 5.

As a further example of buried evidence which supports the effect law space will be given to a related case which also involves yield-depression in a multiple-factor test. This case is found in an investigation by Tolman[4] on the influence of various factors, including nitrogen and phosphate fertilization, on the production of sugar beet seed. The data are pictured in Figs. 5 and 6. In Fig. 5 are shown five yield curves projected on the standard normal yield diagram. Here the curves numbered 1 and 2 represent a combined variety-nitrogen test in which two beet varieties, U. S. 12(618) and A-600(5639)were compared at three levels of nitrogen fertilizer. Curves 3, 4, and 5 were obtained in a test at another location with another variety grown at three levels of nitrogen and three levels of phosphate. These are affected with nitrogen depression.

Besides providing a contrast between normal and depression phenomena in the same district, curves 1 and 2 exemplify the law that identical quantities of a growth factor will produce identical percentages of the maximum yield of any kind of plant (under normal conditions). Thus, observe that in Fig. 5 the ordinate corresponding to 0.75 baule of nitrogen intersects curve 2 at the point corresponding to a yield of 6.55 units. The *A* value of curve 2 is 16, and 6.55 is 40.9% of 16. The same ordinate intersects curve 1 at the 7.34 yield point. The *A* value of curve 1 is 18 and 7.34 is 40.8%

[4]TOLMAN, BION. Sugar beet seed production in southern Utah. U. S. D. A. Tech. Bul. 845, 1943.

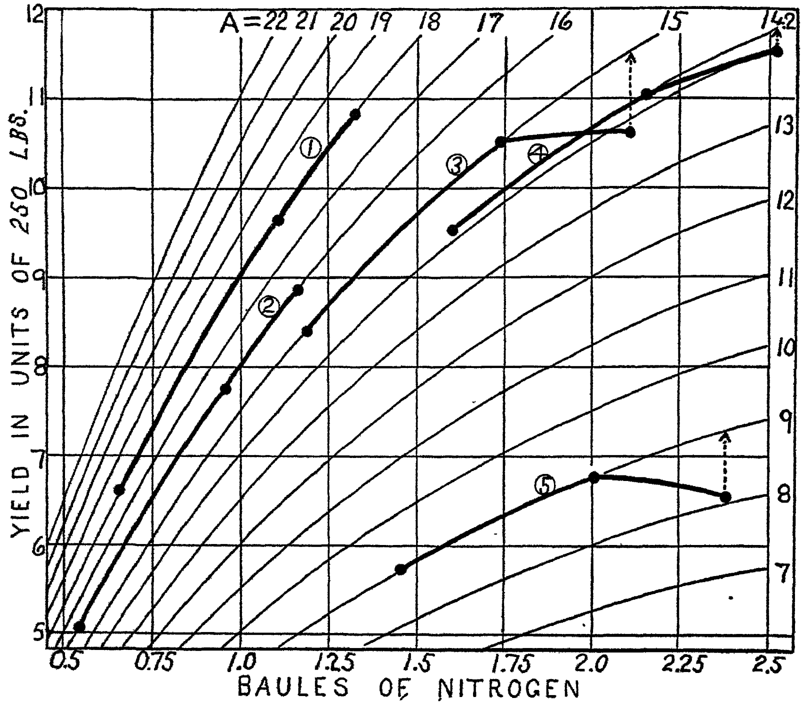

FIG. 5.—Yield curves from Tolman's investigation of sugar beet seed production, illustrating identical requirements of different agrotypes for a plant nutrient (1, 2) and the depressive effect of N in a NP field test (3, 4, 5).

of 18. Following the same procedure with the ordinate corresponding to 1.0 baule of nitrogen, we get the percentage yields of 50.3 and 50.4 in the two cases, and so on with any other ordinate that intersects both curves.

This rule also applies to the normal limbs of curves 3, 4, and 5, but of course does not apply to the disturbed condition represented by the depression limbs of these curves. It should not be forgotten that the normal law of crop increase applies only under *normal* conditions of crop growth. The heretofore prevailing fogginess that has shrouded the Mitscherlich law has been due mostly to the inability of plant biologists and agronomists to distinguish between normal and abnormal yield curves. A ready means of making this distinction is afforded by the standard yield diagram.

The experimental data underlying curves 3, 4, and 5 are presented by Tolman[5] as in Table 3. The data in this table can be regrouped into three series, each showing yields due to nitrogen backed by uniform phosphate fertilization, and three series showing yields due to phosphate backed by uniform nitrogen fertilization. After converting the amounts of ammonium sulfate into equivalent baules,

[5]*Loc cit.*, page 13.

the three nitrogen series are graphed as curves 3, 4, and 5 in Fig. 5. The phosphate series are graphed in Fig. 6. These phosphate curves are depression-free, thus again showing the independence of the phosphate factor from what is happening with the nitrogen factor. The 1000-pound ammonium sulfate series makes a fair fit with curve A = 19, and the 600-pound series fits on curve A = 18.5. The regularity of the curve of the no-nitrogen (untreated) series is somewhat marred by an aberrancy of its middle point, but against the back-

TABLE 3.—*Acre yield of clean seed in a test including three levels of nitrogen and three levels of phosphorus in nine possible combinations.*

Ammonium sulfate, lbs. per acre	Average yields (grams) of seed from plots receiving the indicated amounts of treble superphosphate per acre		
	None	300 lbs.	600 lbs.
None	1,431	2,088	2,395
600	1,677	2,625	2,760
1,000	1,666	2,657	2,877

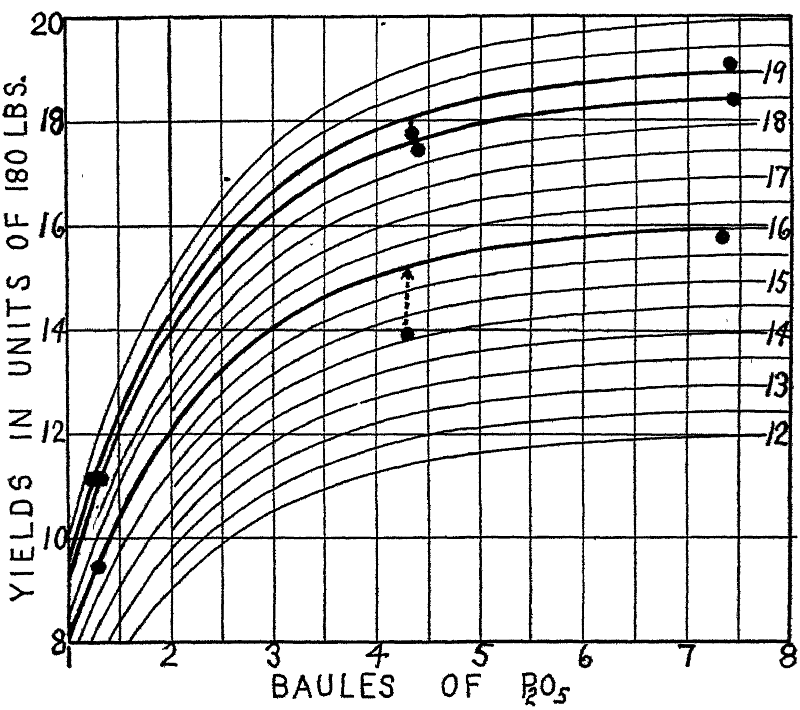

FIG. 6.—Curves of the effect of phosphate at three nitrogen levels in Tolman's field test for sugar beet seed production in which nitrogen caused yield depression. *Lower curve*, no nitrogen; *middle curve*, 600 pounds of ammonium sulfate; and *upper curve*, 1,000 pounds of ammonium sulfate.

ground of the rest of the diagram this aberrancy is insufficient seriously to disturb the conclusion that the action of the phosphate as a whole has followed the effect law, notwithstanding the circumstances that disturbed the action of nitrogen in the same experiment.

SUMMARY

The foregoing discussion gives an agrobiologic analysis of a nitrogen, phosphorus, and potassium field test with potatoes reported by Carolus. When nitrogen was varied while potassium and phosphorus were held constant, the curves of the yields due to nitrogen showed a marked depression effect which became progressively less pronounced where the applications of potassium and phosphorus were progressively increased, but without resulting in a normal yield curve with nitrogen in spite of the use of approximately limit amounts of these two factors. This failure to substitute the nitrogen depression curves by a normal curve is taken as an indication that the nitrogen factor is involved with some physiologic or toxic condition which, if identified and removed, would evidently permit much larger yields. Whatever the cause of the depressive action of nitrogen in this case, it did not act to affect the specific normal nutritive action of potassium and phosphorus, as the yield curves due to these factors conformed to the normal yield equation $y = 120(1-10^{-0.301x})$.

This fact is pointed to as a consequence of the Mitscherlich effect law, which postulates that the effect factor of a growth factor is independent of other cultural conditions. A parallel case is cited in a nitrogen and phosphorus field test with sugar beet seed reported by Tolman, in which the action of nitrogen was depressive while the yield curves due to phosphorus followed a normal course.

Various other details of the graphs of these experiments are pointed out as the natural workings of agrobiologic principles that are necessary consequences of the effect law, including the rule that 1 baule of any factor of plant growth normally has the same yield-increasing potential as 1 baule of any other growth factor, regardless of the kind of plant.

INHERITANCE OF COUMARIN IN SWEET CLOVER[1]

E. H. RINKE[2]

THE desirability of developing a strain of sweet clover, *Melilotus alba*, free from or relatively low in coumarin content has been emphasized by several plant breeders. Coumarin and its related compounds are the substances largely responsible for the "bitter principle" which tends to make sweet clover unpalatable to animals. It is also the substance which is indirectly responsible for the "sweet clover disease of cattle." The symptoms of this disease are a lengthening in the clotting time of the blood and internal hemorrhaging. This condition frequently results in death of the animals.

Investigations had been conducted for several years by various workers at Minnesota in an attempt to develop a strain of sweet clover which was low in coumarin content and possessed desirable agronomic characters for this region. Inbred lines were developed which appeared different in coumarin content and agronomic characters. Some of these lines were crossed and the inheritance of coumarin in various generations of one of these crosses is reported in this paper.

LITERATURE REVIEW

White and Horner (11, 4),[3] using material that showed extreme variation, obtained a highly significant r value for coumarin content of plants tested in the fall of the first year and again at early bud stage the following year. A non-significant correlation coefficient was obtained when the plants tested did not show a wide deviation in coumarin content.

Stevenson and White (10) crossed a high (average coumarin content of progeny 0.41%) by a low (average coumarin content of progeny 0.01%) coumarin plant. The F_1 was intermediate in coumarin content and the F_2 had a bimodal distribution with only a few of the plants being intermediate. A P value of .65 was obtained when the F_2 generation was tested for a 3:1 segregation.

Horner and White (4) tested F_3 progeny from F_2 plants testing 0.00 to 0.05% and found that they usually fell within this range. F_3 progeny from F_2 plants testing above 0.10% either tested uniformly above 0.10% or segregated for high and low. Consequently, they considered plants having 0.05% coumarin as low and those testing 0.10% or more as high.

Horner and White (4) crossed low-coumarin content strains with four strains of high-coumarin content. The F_1's were high in coumarin. They concluded that low-coumarin F_2 plants bred true in F_3, one-third of the high-coumarin F_2 plants gave progeny only of high coumarin content, and two-thirds of the high-coumarin plants were heterozygous for coumarin content. They suggested a one factor differentiation of low from high and also one or more modifying factors which influence coumarin content of the major factor pair.

The alpha type, or sometimes called branch dwarfing type sweet clover, was found in a field of Artic sweet clover (5) and probably is the result of a mutation.

[1]Contribution from the Division of Agronomy and Plant Genetics, University of Minnesota, St. Paul, Minn. Paper No. 2222, Scientific Journal Series, Minnesota Agricultural Experiment Station. Abstracted from thesis submitted to the faculty of the Graduate School of the University of Minnesota in partial fulfillment of the requirements for the degree of Doctor of Philosophy. Received for publication March 19, 1945.

[2]Assistant Professor. The writer wishes to express his sincere appreciation to Dr. H. K. Hayes, Chief of the Division of Agronomy and Plant Genetics, for his direction and guidance in conducting this study. Thanks are also due to Dr. I. J. Johnson, formerly Assistant Professor in the same division, for his advice and guidance during the early phases of this investigation.

[3]Figures in parenthesis refer to "Literature Cited", p. 642.

Elders (2), Kirk (7), Clark (1), and Stevenson (8) all obtained a reasonably good fit to a 3:1 ratio for common type of growth vs. branched dwarfs in studies of F_2 progenies.

Horner and White (4) did not find any evidence of linkage between the factor pair for habit of growth and the main factor pair for high vs. low coumarin content.

MATERIALS AND METHODS

The materials used for the studies of coumarin inheritance and habit of growth were obtained from plant breeding studies carried on at University Farm and Waseca, Minn., respectively.

At University Farm the breeding studies had as their aim the production of a dwarf or Alpha type of sweet clover that was resistant to mosaic and black stem canker and of desirable agronomic type. Alpha plants grow only about half as tall as standard plants and have many more branches arising from the crown than does the standard type. The original material was an Alpha 3 variety selected by Kirk at Saskatoon, Sask., Canada. When grown in Minnesota this variety proved rather susceptible to mosaic and stem canker and the plan of breeding consisted of the selection of disease-resistant plants in selfed lines. The original Alpha type selfed lines used in the study descended from standard type plants in a progeny of Alpha parentage. These plants when selfed, segregated for standard and Alpha type plants. Selection was continued in selfed lines for disease-free Alpha types. Because the Alpha type plants that were selected in these lines were low in seed-setting ability it was decided to cross them with selfed lines having good seed-setting ability. The lines used for crossing were selected at the Waseca station from a standard growth habit variety known as Waseca White. These lines had good seed-setting ability, desirable agronomic characteristics, and resistance to mosaic and stem canker.

After the selfed lines had been selected for several years, crosses were made between various selfed plants and studies of coumarin inheritance and habit of growth were made by comparing selfed progeny of the parent plants with F_1, F_2, and F_3 generation crosses.

Crosses were made under either field or greenhouse conditions by first emasculating by suction (6) and then applying pollen to the stigmas with a toothpick.

The studies of inheritance were made under field conditions in space-planted nurseries. The plants grown in the field were started in the greenhouse the first part of March and transplanted in May into rows spaced 3 feet apart with the plants separated by 3 feet in the row.

Plants grown to maturity in the greenhouse were started from seed sown in pots the latter part of October and brought into bloom in about 6 weeks by keeping soil moisture at a minimum, growing under artificial light for 18 hours a day, and maintaining the temperature at 70° F.

The first crosses were made in the field in 1937 using as parents 2-year selfed lines of Alpha type and 2-year selfed lines of standard type. The F_1 plants and selfed progeny of the parent selfed lines were grown in the greenhouse in the winter of 1937–38 and selfed seed was obtained. This seed was used to plant selfed progeny of the parents and the F_2 generations in the field in the spring of 1938. This material was used to study coumarin inheritance of 422 plants during the first year of growth and of these same plants during the following year of growth. F_1 and F_2 generation plants were analyzed for coumarin content during two seasons. The correlation coefficients for individual families and the total population were calculated. This study was made to learn whether determinations during the first year of growth were of value in estimates of coumarin content in the second year of growth.

Crosses were made in the winter of 1937–38 between 3-year selfed lines of dwarf and standard habit. The F_1 crosses and their parents were selfed in 1939 under field conditions. In 1940–41 plants of parental selfed lines as well as F_1 and F_2 progenies were grown under field conditions. This material furnished further opportunity to determine the mode of inheritance of coumarin content and habit of growth.

The method used to show genetic relationships of the parents and progeny will be illustrated as follows: The original plant used as a source of all Alpha material was selfed and its first year selfed progeny was designated S31. Three

first year selfed plants were labeled S31-2, S31-3, and S31-4, respectively. A third year selfed line of S31-3 was labeled S31-3-12. A fourth generation selfed line was labeled S31-3-12-15A. Crosses are designated as S31-3-12-1 ×C19-1-18-1, which represents a cross of plant 1 in a 3-year selfed line of S31-3-12 with plant 1 in a third generation selfed line of C19-1-18, of Waseca White parentage.

METHODS OF SAMPLING

Approximately 120 mature leaflets were picked from the area within 4 to 12 inches from the growing point of the stems of each plant. Care was taken to sample several branches of each plant. The leaves from a plant were thoroughly mixed, 1-gram samples were weighed and immediately placed in a glass vial, stoppered, and stored at –10°C until time of analysis. Samples representing the first year of growth were taken from July 16 to 20. Second year growth was sampled between late bud and early flowering stages. The accuracy of the method of sampling was determined by analyzing the coumarin content of duplicate samples from 131 plants. The standard error of a single determination was .05.

METHOD OF ANALYSIS

The method of analysis used (3) is based on Robert's modification of that reported by Stevenson and Clayton (9). The term coumarin as used in this paper includes coumarin, coumaric acid, melilotic acid, and other phenolic bodies, and is reported on a green weight basis. A standard solution containing 0.10 mg of coumarin was carried through all procedures with each group of samples as a check on technic.

The percent coumarin in the 1938 tissue samples was determined by matching by eye the unknown concentrations against standard solutions. When a considerable number must be matched, the eye soon becomes fatigued and inaccuracies occur. This method also necessitates the preparation of new series of standard solutions every few days. In order to eliminate these two difficulties a photoelectric colorimeter constructed by the University of Minnesota Scientific Laboratory was used to determine intensity of color in later work.

A glass filter transmitting light of the wave length 330 to 600 millimicrons with an optimum transmission of 470 millimicrons was inserted between the light source and the coumarin solutions. The cells used for holding the solution were made of matched optically ground glass and were 15 mm × 55 mm × 55 mm. The galvanometer used for measuring the amount of light reaching the photo-electric cell was of the ordinary needle type with a scale of from 0 to 100 milliamperes. The intensity of the color was recorded as galvanometer deflection.

The galvanometer deflections for a series of 13 standard solutions were plotted on semilogrithmic paper against the known coumarin concentrations of the standard solutions. A quadratic regression line was fitted to the actual data and by using the quadratic regression data, conversion charts were prepared for transforming the galvanometer readings to percentage coumarin.

ENVIRONMENTAL EFFECT ON COUMARIN CONTENT

Isolated seed increase plots of F_3 progeny, obtained from F_2 Alpha type plants of desirable agronomic characteristics, were grown at University Farm in central Minnesota and at Waseca in southern Minnesota in 1940–41. These seed increase plots were a part of the Experiment Station's sweet clover improvement project. Five of the F_3 families grown in these plots were also grown in the sweet clover breeding nursery at University Farm the same season. These five families presented the opportunity to study by means of t tests, the effects of environmental conditions on similar material when grown at University Farm and at Waseca, and also to study the effect of differences in soil fertility on coumarin content when grown in two different fields at University Farm.

CLASSIFICATION OF GROWTH HABIT

The F_2 populations in 1939 and 1941 were classified into four plant types, namely, standard, intermediate standard, intermediate Alpha, and Alpha. This material was studied for segregation of growth habit.

The relationship of plant type and coumarin content was studied in the F_2 families 48 and 49 by using the X^2 test for independence.

Values on tests of significance or association which have less than 1 chance out of 20 as being due to chance alone are indicated by an asterisk (*). Values which have less than 1 chance out of 100 as being due to chance alone are indicated by the double asterisk (**).

EXPERIMENTAL RESULTS

COUMARIN CONTENT OF FIRST AND SECOND YEAR GROWTH

The correlation coefficients of 17 individual families and of the total population of 422 plants studied for coumarin in the first and second year growth are presented in Table 1.

TABLE 1.—*Correlation of coumarin content for first year growth with coumarin content for second year growth for individual cultures and total population.*

Culture No.	No. of plants	r	Culture No.	No. of plants	r
S-14a	15	-.29	S-19	14	-.30
S-15	17	.13	S-20	5	-.71
S-15a	28	.66**	S-23	5	.34
S-16	11	.42	S-24	7	-.35
S-22	56	-.07	S-201	16	.29
S-17a	18	.34	S-1	63	.10
S-17	18	.20	S-2	44	.22
S-18	28	.30	S-3	57	.25
S-21	20	.49*			
			Total	422	+.24**

*Significant.
**Highly significant.

The correlation coefficient for S-21 reached the level of significance for the 5% point and the correlation coefficients for S-15a and the total population reached the level of significance for the 1% point. All other values are nonsignificant. Although r for the total population is significant, the correlation of +.2358 is so small that it accounts for only about 6% of the total variation in coumarin content. On the average, coumarin content was higher in tests on first year growth than on second year growth.

INHERITANCE OF COUMARIN CONTENT

The parental progenies, F_1 generation, F_2 generations, open-pollinated Alpha 3, and common biennial white are placed in frequency distribution classes for percentage coumarin in Table 2.

The coumarin content of the parents of each of the crosses studied was determined by comparing the coumarin content of the selfed progeny of the plants used in making the crosses with the coumarin content of the segregating generations. In the cross S-31-3-12 × C-19-1-18, the coumarin content of the parent S-31-3-12, as indicated by its selfed progeny, had a 1939–41 mean value of 0.186±.009% and was fairly homozygous for relatively low coumarin content. The other parent had a mean coumarin content of 0.511±.020%

TABLE 2.—*Frequency distribution of percentage of coumarin of individual plants of the parental progeny, F_1, F_2, Alpha 3, and common biennial white sweet clover.*

Cultures	Pedigree	Years selfed	Class frequencies in hundredths of a per cent coumarin												Total No. of plants	Percentage coumarin mean
			0–04	05–09	10–14	15–19	20–24	25–29	30–34	35–39	40–44	45–49	50–54	55–60		
							1939 Data									
Parent	S-31-3-12	3														
Parent progeny	S-31-3-12-15a	4			6	11	10	1	4						32	0.196±.011
Parent	C-19-1-18	3														
Parent progeny	C19-1-18-17a	4							1		2	1	4	9	17	0.531±.020
F_1 generation	S-24				3	4		1							8	0.159±.016
							1941 Data									
Parent progeny	S-31-3-12-15a	4		1	3	5	1	1							11	0.157±.017
Parent progeny	C-19-1-18-17a	4							1	1			2		4	0.428±.022
F_2 generation	S-24-48 to 53	1		9	47	90	103	74	45	27	16	4	2	1	418	0.238±.004
							1939 Data									
Alpha No. 3	S-20	0				1		3		1	1				6	0.29±.031
Common biennial white		0	5	5	5	3	1		2			1			22	0.13±.024

and appeared relatively homozygous for high coumarin. The F_1 generation had a mean value of 0.159±.016% and in this cross relatively low coumarin content appeared dominant over relatively high coumarin content.

The curve of the F_2 generation shows only a single mode so there is little evidence regarding the number of factors involved. The F_2 generation may be placed into two classes represented by the range of the coumarin content of the selfed parental progeny, grown the same year as the F_2 generation. This gives the classes .06–.29 for the low coumarin and .30–.60 for the high. In the F_2 generation 22.7% of the plants fall into the class .30–.60 and 77.3% in the range of the low coumarin parent. Therefore, it seems probable that only a single major pair of factors is involved in the inheritance of coumarin content.

Culture S-20 which consisted of open-pollinated plants of Alpha No. 3 had a mean coumarin percentage value of 0.29±.031 which is a higher content than in some of the selfed lines. Common biennial white, an open-pollinated variety, had a mean coumarin percentage value of 0.13±.024. This open-pollinated variety was relatively low in coumarin content, considerably lower than selfed lines of Waseca White, and gave a distribution somewhat similar to the F_2 population.

ENVIRONMENTAL EFFECT ON COUMARIN CONTENT

Five F_3 families were tested for coumarin content when grown at three locations. Their mean coumarin content and t values obtained when tested for significant difference are presented in Table 3.

As indicated by the "t" test, all of the cultures were significantly or highly significantly different when comparisons were made between University Farm field X and University Farm field E or field E and Waseca. None of the cultures differed significantly when comparisons were made between field X and Waseca. The correlation coefficients +.977 and +.975 obtained in studying association of coumarin content at Waseca with fields E and X at University Farm are significant values. In the comparison of field E vs. field X at University Farm an r of .813 was obtained, whereas an r of .878 is needed to reach the 5% point of significance. Although coumarin content was significantly influenced by environment, there still remained a high degree of association from one field to the next.

INHERITANCE OF GROWTH HABIT

The F_1 plants from crosses between Alpha and standard growth types are of a standard type thus indicating dominance of standard over Alpha growth type. A wide range of variation occurred in the F_2 population and it was classified on the basis of four plant types. This classification scheme did not consistently fit any genetic ratio for segregation of characters, probably due to the inability to accurately classify intermediate types of plants.

GROWTH TYPE VS. COUMARIN CONTENT

Cultures 48 and 49 grown in 1940–41 were studied for independence of growth habit and coumarin content. Data are presented in Table 4.

TABLE 3.—*Average percentage coumarin content, t values, and correlation coefficients for five F_3 progenies grown at three locations.*

Culture No.	Location	No. of plants	Average percentage coumarin	"t" values Univ. Farm field E vs.		"t" values Univ. Farm field X vs. Waseca
				Univ. Farm field X	Waseca	
29-4	U. Farm—E U. Farm—X Waseca	35 13 23	0.30±.019 0.18±.012 0.20±.019	3.47**	3.50**	1.08
42-57	U. Farm—E U. Farm—X	28 12	0.34±.018 0.17±.012	4.83**	—	—
54-7	U. Farm—E U. Farm—X Waseca	38 22 13	0.24±.011 0.14±.016 0.13±.020	5.22**	4.80**	0.65
5-8	U. Farm—E U. Farm—X Waseca	29 16 14	0.36±.018 0.29±.032 0.26±.030	2.84**	3.08**	0.25
44-60	U. Farm—E U. Farm—X Waseca	20 5 23	0.25±.020 0.14±.024 0.12±.014	2.18*	5.03**	0.92

*Significant.
**Highly significant.

TABLE 4.—*X^2 for independence of growth habit and coumarin content.*

Classes for growth habit	Coumarin classes in 1/100 of 1%			
	0-14	15-29	Above 30	Total
Standard	8	24	7	39
Intermediate standard	11	28	17	56
Intermediate Alpha	9	31	11	51
Alpha	1	14	11	26
Total	29	97	46	172

$X^2 = 8.2410$ P = approximately .20

X^2 for independence equals 8.2410 which gives a P value of approximately .20. This indicates that coumarin content and growth habit are inherited independently of each other as a variation as great as the observed would be expected to occur about 20 times out of 100 due to chance variation alone.

SUMMARY

A study was made of the manner of inheritance of coumarin content of sweet clover in a cross between inbred lines that differed in coumarin content. Inheritance of the dwarf branching habit also was

studied in the same cross. The analytical method used to determine coumarin content does not separate coumarin, coumaric acid, melilotic acid, and other phenolic bodies from one another so the term coumarin as used in this study includes these substances and is reported on a green weight basis.

In the cross studied the mean coumarin content of the F_1 generation approached closely the mean coumarin content of the low coumarin parent and it appeared that in this cross relatively low coumarin was dominant over high coumarin. Approximately 77% of the F_2 population fell in the range of the low coumarin parent and 23% in the range of the high coumarin parent when all the material was grown the same year. Therefore, it seems probable that a single major factor pair is involved in the inheritance of coumarin content. The distribution of the F_2 population was not bimodal.

F_3 lines from selfed plants of the Alpha type were grown in two different fields at University Farm and also at Waseca in southern Minnesota. The mean coumarin values for field E were significantly higher than the mean coumarin values in the other field or location. The degree of association of coumarin content between the different fields and locations as indicated by r exceeds or closely approaches the 5% point of significance.

A highly significant correlation coefficient of $+.2358$ indicates that it was not possible within the range of coumarin content studied to determine accurately the coumarin content of second year growth by measuring the coumarin content during July of the first year's growth. Growth habit and coumarin content do not appear to be associated with each other on the basis of a study by the X^2 test for independence.

LITERATURE CITED

1. CLARKE, A. E. Inheritance of the dwarf branching habit in sweet clover. Sci. Agr., 11:326. 1931.
2. ELDERS, A. T. The dwarfing character in sweet clover. Sci. Agr., 8:438. 1928.
3. HAYES, H. K., and IMMER, F. R. Methods of Plant Breeding. Ed. 1, 432 pages, illus. New York: McGraw-Hill Book Co., Inc. 1942.
4. HORNER, W. H., and WHITE, W. J. Investigations concerning the coumarin content of sweet clover, III. The inheritance of the low coumarin character. Sci. Agr., 22:85. 1941.
5. KIRK, L. E. Alpha sweet clover. Univ. of Saskatchewan. Agr. Ext. Bul. 45. 1929.
6. ————. Abnormal seed development in sweet clover species crosses—a new technique for emasculating sweet clover flowers. Sci. Agr., 10:321. 1930.
7. ————. Inheritance of the dwarf branching habit in sweet clover. Sci. Agr., 11:315. 1931.
8. STEVENSON, T. M. Sweet clover studies on habit of growth, seed pigmentation, and permeability of the seed coat. Sci. Agr., 17:627. 1937.
9. ———— and CLAYTON, J. S. Investigations relative to the breeding of coumarin-free sweet clover, *Melilotus*. Can. Jour. Res., C, 14:153. 1936.
10. ———— and WHITE, W. J. Investigations concerning the coumarin content of sweet clover. I. Breeding of a low coumarin line of sweet clover. Sci. Agr., 21:18. 1940.
11. WHITE, W. J., and HORNER, W. H. Investigations concerning the coumarin content of sweet clover. II. Sources of variation in tests for coumarin content. Sci. Agr., 21:29. 1940.

REGISTRATION OF VARIETIES AND STRAINS OF OATS, XIV[1]

T. R. STANTON[2]

THE thirteenth consecutive report on the registration of improved oat varieties was published in May 1944.[3] During the past year, only one variety, described below, was submitted and approved for registration.

Group and Varietal Name	Reg. No.
Midseason white:	
Mission	104

Mission (C. I. 2588)[4] originated from a cross between Markton and Victory made at the Aberdeen Substation, Aberdeen, Idaho, by G. A. Wiebe in 1923. From this same cross, the previously registered Bannock, Huron, and Bridger varieties were derived.[5]

Some of the most vigorous selections from this cross that had been resistant to smut in tests at Aberdeen were sent to the Montana Agricultural Experiment Station at Bozeman and its branches at Havre and Moccasin, Montana, in 1929, where several of the most promising selections have been tested up to and including 1944. Among these selections is C. I. 2588, which proved to be superior in yield, quality, stiffness of straw, and resistance to smut. It was primarily through the continued good performance at the North Montana Branch Station at Havre that Mission was selected as an improved variety for dry land production. It was named Mission in 1944, and is being increased in Montana for distribution to farmers for growing principally on dry land. Mission is a product of cooperative research between the Division of Cereal Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering, and the Idaho and Montana agricultural experiment stations. Many workers had a part in its development.

The application for the registration of Mission was submitted by S. C. Litzenberger and Royse P. Murphy, Montana Agricultural Experiment Station, Bozeman, Mont., who furnished brief descriptive notes on the variety in addition to data on yield and quality.

Mission is a medium tall, early to midseason oat of the *sativa* type, with spreading panicles, a relatively stiff straw, and plump white

[1]Registered under cooperative agreement between the Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture, and the American Society of Agronomy. Received for publication May 26, 1945.

[2]Senior Agronomist, Division of Cereal Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering, member of the 1944 committee on Varietal Standardization and Registration charged with the registration of oat varieties.

[3]STANTON, T. R. Registration of varieties and strains of oats, XIII. Jour. Amer. Soc. Agron., 36:445–446. 1944.

[4]C. I. refers to accession number of the Division of Cereal Crops and Diseases.

[5]STANTON, T. R. Registration of varieties and strains of oats, VIII, X, and XII. Jour. Amer. Soc. Agron. 30:1030–1036, 1938; 33:246–251, 1941; and 35:242–244, 1943.

kernels. It is highly resistant to the races of loose and covered smuts of oats found in Montana.

The average acre yield and test weight of Mission, Gopher, and Bridger, obtained for various periods on dry land at four stations and on irrigated land at three stations in Montana are given in Table 1.

TABLE 1.—*Average yield and test weight for Mission, Gopher, and Bridger oats grown in replicated yield experiments at various locations on dry and irrigated land in Montana for the period of years indicated.*

Location	Number of years grown	Mission C. I. 2588 (new)		Gopher C. I. 2027 (standard, dry land)		Bridger C. I. 2611 (standard, irrigated)	
		Test weight, lbs. per bu.	Grain yield, bu. per acre	Test weight, lbs. per bu.	Grain yield, bu. per acre	Test weight, lbs. per bu.	Grain yield, bu. per acre
				Dry Land			
Havre...	10	35.4	41.1	33.5	40.7	—	—
Huntley.	1	35.2	103.0	34.0	96.1	32.1	95.0
Kalispell	3	33.7	84.2	31.1	81.8	31.2	82.9
Moccasin	5	36.1	49.1	34.3	47.4	—	—
				Irrigated			
Bozeman	5	39.9	121.3	39.1	130.9	39.1	147.7
Corvallis	2	38.6	109.7	39.3	113.8	39.5	125.2
Huntley	1	35.8	92.9	35.3	94.9	39.3	90.1

Mission combines the excellent grain characters of Victory with the smut resistance of Markton. Under irrigation, it has been the equal of Gopher and Bridger in test weight, but has been less productive. On dry land, Mission has been superior both to Gopher and Bridger in test weight and yield which, together with its shorter straw and earlier maturity, makes it a more desirable dry land variety than the later, taller, and larger strawed Bridger. For further yield data on Mission, see reports by Coffman.[6]

[6]COFFMAN, F. A. Results from the cooperative coordinated oat breeding nurseries for 1942, and the uniform winter-hardiness nurseries for 1942–43, U. S. D. A., Mimeograph publication. 1943.

BARLEY VARIETIES REGISTERED, X[1]

H. K. HAYES[2]

SIXTEEN varieties of barley have been approved for registration previous to this report, one variety having been registered in 1943, the last report appearing in the JOURNAL in May 1944.[3] An additional variety named Reno has been approved for registration. The following brief history is quoted from Swanson and Laude.[4]

RENO, REG. NO. 17

"Reno is the principal variety of winter barley grown in Kansas. It is not a pedigreed strain, but comes from selected heads from the adapted strain known as 'Southcentral' from the farm of J. A. Johnson of Hutchinson, Kansas. The selected heads were increased by Walter C. Peirce of Hutchinson, in cooperation with the experiment station. The first farm supply of seed was distributed by Mr. Peirce after approval for certification in 1939. Reno is a six-rowed, lax-headed, strong-awned variety, and is most winterhardy and the highest in yield of the winter types tested in Kansas. The plants tiller freely and lodge rather easily."

Comparative yields of Reno and Missouri Early Beardless have been made in south central and southeastern experimental fields in the region that was considered by Swanson and Laude to be best adapted to winter barley. The results of these trials and of trials made at Manhattan, Kans., are summarized in Table 1.

TABLE 1.—*Comparative yield in bushels per acre of Reno and Missouri Early Beardless winter barleys in various trials in south central and southeastern Kansas and at Manhattan, Kans.*

Name of field	Years tested	Yield, bushels per acre	
		Reno	Missouri Early Beardless
South Central Kansas			
Wichita	6	41.3	33.2
Kingman	7	23.1	17.3
Hutchinson	2	34.7	21.7
Southeastern Kansas			
Columbus	7	34.8	21.2
Thayer	4	25.7	18.7
Manhattan	7	20.2	14.1

[1]Registered under a cooperative agreement between the Bureau of Plant Industry, Soils and Agricultural Engineering, U. S. Dept. of Agriculture, and the American Society of Agronomy. Received for publication May 26, 1945.

[2]Chief, Division of Agronomy and Plant Genetics, Department of Agriculture, University of Minnesota, St. Paul, Minn. Member of committee on Varietal Standardization and Registration of the Society charged with the registration of barley varieties.

[3]HAYES, H. K. Barley varieties registered, IX. Jour. Amer. Soc. Agron., 36:444. 1944.

[4]SWANSON, A. F., and LAUDE, H. H. Barley production in Kansas. Kans. Agr. Exp. Sta. Bul. 318. 1943.

REGISTRATION OF IMPROVED FLAX VARIETIES, III[1]

A. C. ARNY[2]

IN THE first report on registration of improved varieties of flax, published in the September 1943 issue of the JOURNAL, two varieties were described. In the second report, published in the May 1944 issue of the JOURNAL, two additional varieties were described. Three varieties, Arrow, Renew, and Koto, have been approved for registration in 1944.

ARROW REG. NO. 5

Arrow (C.I. 1070) was developed through cooperation between the Montana Agricultural Experiment Station and the Division of Cereal Crops and Diseases, U. S. Dept. of Agriculture. This new variety is a selection from a cross between Bison and Renew made by A. C. Dillman at Bozeman in 1938. The selection from which Arrow was developed was made from the F_3 generation in 1940. It was tested at the Montana, North Dakota, and Minnesota experiment stations and found to be immune to North American races of rust, *Melampsora lini*, and to have resistance to wilt, *Fusarium lini*, and pasmo, *Sphaerella linorum*, similar to the Bison parent. The plants are mid-height, 24 to 30 inches, relatively resistant to lodging, and midseason in maturity. The flowers are funnelform with deep blue petals similar to those of Bison. The bolls are semidehiscent, the septa ciliate. The seeds are brown, midsize, 5.0 to 7.5 grams per 1,000 seeds, and the oil content and iodine number of the oil satisfactory.

Based on yield tests (Table 1), Arrow was placed on the recommended list for seed production in all flax-growing areas of Montana. Increases during the winter of 1942–43 at the Imperial Valley Experiment Station, El Centro, Calif., and under irrigation near Bozeman in 1943, provided 18,000 pounds of foundation seed for distribution to growers of certified seed in Montana for planting in 1944.

RENEW REG. NO. 6

Renew (C.I. 839) was developed cooperatively by the Division of Cereal Crops and Diseases, U. S. Dept. of Agriculture, and the Northern Great Plains Field Station, Mandan, N. Dak. J. C. Brinsmade made the cross Newland × (Reserve × Morye) in 1930 to combine the rust resistance of Newland with the wilt resistance of the hybrid, Reserve × Morye. Selections were made in 1934 and planted in triplicate 5-foot rows in the wilt nursery at Mandan in 1935. Renew was one of these selections. Renew is immune to races

[1]Registered under cooperative agreement between the Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture and the American Society of Agronomy. Received for publication May 26, 1945.

[2]Associate Agronomist, Division of Agronomy and Plant Genetics, Department of Agriculture, Forestry and Home Economics, University of Minnesota, St. Paul, Minn. Member of Committee on Varietal Standardization and Registration of the Society charged with the registration of flax varieties.

TABLE I.—*Yields in bushels per acre of Bison, Koto, Renew, and Arrow flax in replicated three-row plots under irrigation and on dry land stations in Montana.*

Year grown	Bison	Koto	Renew	Arrow	Sig. difference at 5% point
			Bozeman*		
1940	31.8	33.7	28.6	—	6.0
1941	37.1	34.5	38.5	—	5.0
1942	28.5	29.2	25.6	—	7.9
1943	36.8	37.2	34.2	37.1	4.9
1944	30.2	24.2	28.4	29.8	6.3
Av.	32.9	31.8	31.1	—	2.7
			Huntley*		
1944	21.9	20.4	19.8	24.5	3.9
			Moccasin		
1940	4.3	4.9	4.3	—	1.3
1941	8.8	2.9	8.7	—	3.5
1942	15.0	12.2	15.4	—	2.4
1943	7.8	6.9	9.3	6.7	2.5
1944	13.4	12.6	16.4	15.4	4.1
Av.	9.9	7.9	10.8	—	1.3
			Havre		
1942	10.5	11.4	10.8	—	2.3
1943	13.9	11.3	12.6	8.3	2.6
1944	6.0	5.5	6.5	5.1	2.4
Av	10.1	9.4	10.0	—	1.4
			Froid		
1943	13.3	12.1	16.2	17.4	3.4
1944	11.9	13.4	20.3	18.9	5.3
Av.	12.6	12.8	18.3	—	3.2
			Cooperative Nurseries†		
1943	12.3	—	17.4	16.1	—
1944	8.6	—	11.3	10.2	—
Av.	10.5	—	14.4	13.2	—

*Irrigated at Bozeman and Huntley.
†Average of six nurseries in 1943 and eight nurseries in 1944 located in northeastern Montana.

of rust common in North America at the present time, only moderately resistant to wilt, and susceptible to pasmo.

The plants are mid-height, 22 to 28 inches, resistant to lodging, and early in maturity. The flowers are funnelform with blue petals; the bolls are semi-dehiscent and the septa smooth; the seeds are brown and midsize, 5.0 to 6.0 grams per 1,000; the oil content of the seed and the iodine number of the oil are medium to high.

Yield data for Renew in comparison with Bison are given in Tables 1, 2, and 3. Based on these yields, Renew is recommended for seed production in North Dakota and Montana.

TABLE 2.—*Average yields in bushels per acre of Renew, Bison, and Koto at certain stations in North Dakota for the years indicated.*

Variety	North Dakota plot tests, drilled	
	Fargo, 1940–44	Four stations, 1943–44*
Renew	14.7	17.8
Bison	13.2	13.8
Koto	—	17.5

*Edgeley, Langdon, Dickinson, and Williston.

KOTO REG. NO. 7

Koto (C.I. 842) was developed by the Division of Cereal Crops and Diseases, U. S. Dept. of Agriculture, in cooperation with the Northern Great Plains Field Station at Mandan, N. Dak. J. C. Brinsmade, in 1930, crossed (Reserve, C.I. 19 × Morye, C.I. 112) × Bison and a selection grown in triplicate 5-foot rows on wilt-infested soil at Mandan in 1935 was assigned the C.I. No. 842 and later named Koto.

The plants of Koto are midheight, 24 to 30 inches, resistant to lodging, and midseason in maturity. The dark blue flowers are funnelform; the bolls, semidehiscent; the septa ciliate; seeds brown, midsize, 5 to 6 grams per 1,000; oil content of seed and iodine number of oil satisfactory; straw and fiber yields satisfactory. Koto is susceptible to one or more of the North American races of rust. It is similar in wilt and pasmo reaction to its Bison parent.

Yields obtained at five stations in the Dakotas and Minnesota are given in Table 3.

TABLE 3.—*Average and relative yields, compared with Bison, of six varieties of flax grown in three-row plots in triplicate at Fargo and Park River, N. Dak.; Crookston and Morris, Minn.; and Brookings, S. Dak., during the period 1939–44, inclusive.*

Variety	Yield per acre, bu.						
	Fargo, 1939–44	Park River, 1941–44	Crookston, 1940–44	Morris, 1939–44	Brookings, 1939–44	Average	Percentage of Bison
Bison	13.9	19.7	16.2	15.1	14.7	15.9	100
Biwing	16.4	22.4	15.4	20.3	15.2	17.9	113
Redson	16.4	23.7	16.0	18.9	17.2	18.4	116
Crystal	15.8	27.0	13.0	22.0	16.9	18.9	119
Renew	15.7	25.0	16.4	20.9	16.6	18.9	119
Koto	17.2	22.4	19.2	20.9	17.7	19.5	123

In 1943, Koto was put on the recommended lits of varieties for use in Minnesota, North Dakota, and South Dakota. In 1944, about 2,000 acres of Koto were grown in North Dakota, 400 acres in Minnesota, and 250 acres in South Dakota.

REGISTRATION OF VARIETIES AND STRAINS OF ALFALFA, I[1]

E. A. HOLLOWELL[2]

DISEASES, insect pests, and different climatic hazards limit successful alfalfa production unless adapted improved varieties are used. The progressive alfalfa grower is now asking for specific varieties for his particular conditions. A number of alfalfa breeding and improvement programs were underway before World War I, but these received a serious set-back during that war. One of the few programs which continued was at Michigan where F. A. Spragg and co-workers succeeded in producing a superior variety, Hardigan. During this period a number of varieties, strains, and introductions were identified and these were widely tested by state agricultural experiment stations and the Bureau of Plant Industry during the decade beginning in 1920. These tests evaluated the characteristics and determined the range of adaptation of such varieties and strains as Grimm, Baltic, Cossack, Ladak, Kansas Common, Hairy Peruvian, and others.

The isolation, in 1925, of the organism *Corynebacterium insidiosum* which causes the serious bacterial wilt disease gave a new and greater impetus to alfalfa improvement. Studies indicated this disease could be effectively controlled only through the use of resistant varieties. These improvement programs had their beginning in the search by H. L. Westover for bacterial wilt resistant strains in Turkistan, Asia, in 1929. Investigations indicated that resistant strains could be obtained by selection within certain strains or by combining the disease resistance of introduced strains with the more desirable characteristics of domestic varieties resulting in greater forage and seed yields. The Alfalfa Improvement Conference, organized in 1935, played an important part in evaluating new strains in over 40 states and several Canadian provinces. The Conference also served as an agency to focus attention on the problems involved and to correlate the work in many ways.

Methods of procedure and regulations had been developed by certifying agencies under which seed of alfalfa varieties could be increased without becoming contaminated by strains having inferior characteristics. The need for seed certification of superior alfalfas is emphasized by the recent finding of the high percentage of cross

[1]Registered under a cooperative agreement between the Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture, and the American Society of Agronomy. Received for publication May 26, 1945.

[2]Senior Agronomist, Division of Forage Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture. Member of the 1944–45 committee on Varietal Standardization and Registration charged with the registration of alfalfa varieties. Acknowledgment is made to Dr. H. M. Tysdal, Division of Forage Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture, for the preparation of the introductory statement.

pollination effected by bees and by the results of genetic studies indicating that the F_1 of a cross between a plant resistant to the bacterial wilt disease and a susceptible plant is intermediate in resistance. Subsequent tests have similarly shown that when a resistant and a susceptible strain are grown side by side in the field the seed from the resistant strain has about half the disease resistance of the resistant parent. The International Crop Improvement Association has effectively cooperated with the Alfalfa Improvement Conference and the originating stations in the increase of certified seed of some of these new strains. This effective cooperation among the plant breeders, seed certifying agencies, and other organizations hastens the development of improved varieties and makes possible the rapid increase of superior seed for farm use.

RANGER, REG. NO. 1

Ranger is a synthetic variety developed by compositing the five strains A-110, A-111, A-116, A-117, and A-119 as numbered and tested in the Uniform Alfalfa Nursery Trials (4, 5, 6, 7, 8).[3] The origin of the strains was inbred lines subsequently outcrossed among other selected lines from the Cossack, Turkistan, and Ladak varieties in the proportion of 45, 45, and 10%, respectively. The strains were developed by H. M. Tysdal and were composited in 1940 after having been selected and tested over a period of 10 years. G. L. Peltier cooperated on the early phases of selection for resistance to bacterial wilt, and T. A. Kiesselbach and H. L. Westover provided materials and assisted in methods of procedure.

Ranger, *M. media*, was developed cooperatively by the Nebraska Agricultural Experiment Station and the Division of Forage Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering, U. S. Dept. of Agriculture, and was first commercially released in 1942. It is resistant to bacterial wilt, *Corynebacterium insidiosum*, is winterhardy, and has a variegated flower color with a limited number of yellow-colored flowers. Ranger is slightly more susceptible to leaf spot diseases, *Pseudopeziza medicaginis* and *P. jonesii*, and leafhopper, *Empoasca fabae*, attacks than such standard varieties as Grimm and Hardigan, but it is considerably more resistant than the varieties of Turkistan origin. In seed production Ranger is equal to the varieties of Grimm, Cossack, and Baltic, and is superior to varieties of Turkistan origin.

Ranger is adapted to the northern states, particularly where bacterial wilt causes stand losses. Where bacterial wilt is not a factor in maintaining stands, the yield of Ranger is approximately the same as, or slightly less than, the best adapted varieties in the northern states. The yields as given in Table 1 are from stands established in 1940.

At Ames, Iowa, bacterial wilt had caused stand reductions, the effect of which is shown in the yield data. Results presented in a more recent publication (9) also show the effect of the disease on established stands. Over 30 thousand pounds of certified seed of Ranger alfalfa were produced in 1944.

---

[3]Figures in parenthesis refer to "Literature Cited", p. 652.

TABLE 1.—*Comparative hay yields in tons per acre of Ranger compared with other standard alfalfa varieties at different locations, 1943.*

Variety	Columbus, Ohio	Ames, Iowa	Beltsville, Md.	Lincoln, Nebr.	Aberdeen, Idaho
Ranger	2.75	3.55	2.85	4.99	9.33
Grimm	3.17	2.47	2.90	4.59	9.15
Hardistan	2.44	3.47	2.28	4.76	9.49
Kansas Common	3.08	1.75	2.28	4.65	8.75
Ladak	—	3.01	—	4.79	—

BUFFALO, REG. NO. 2

Buffalo, a bacterial wilt resistant selection from the variety Kansas Common, was made by C. O. Grandfield in 1932. This selection was tested for 8 years in the Uniform Alfalfa Nurseries (7, 8) under the number A-11. Buffalo, *M. sativa*, was developed cooperatively by the Kansas Agricultural Experiment Station and the Division of Forage Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering, U. S. Dept. of Agriculture, and was first commercially released as a variety in 1943. It is highly resistant to bacterial wilt, *Corynebacterium insidiosum*, has purple-colored flowers, is high yielding, and is similar to Kansas Common in all other respects, being generally adapted to the central and southern states where Kansas Common is recommended. From limited tests, however, it appears to be slightly more winterhardy than Kansas Common. Yield and stand data and a discussion of the characteristics are given in Table 2 and elsewhere (1, 2, 9).

TABLE 2.—*Comparative hay yields and stands of Buffalo compared to Kansas Common at Manhattan, Kans., for the years 1939–42.*

Variety	Yields, tons per acre				Stand survival, %	
	1939	1940	1941	1942	1939	1942
Buffalo	3.26	4.01	3.53	3.26	95	95
Kansas Common	3.69	4.22	3.18	2.53	100	25

Foundation seed of Buffalo is being increased and distributed by the Kansas Agricultural Experiment Station. Approximately 1,200 pounds of certified seed were produced in 1944.

MEEKER BALTIC, REG. NO. 3

Meeker Baltic is a natural selection from the variety Baltic developed during the period 1914–29 in western Colorado. A complete discussion of its origin is given by Robertson, *et al.* (3). Meeker Baltic, *M. media*, has variegated flower color, is winterhardy, and is high yielding. It is susceptible to the bacterial wilt disease, *Corynebacterium insidiosum*. Meeker Baltic was tested for 10 years and named by the Colorado Agricultural Experiment Station, and was first distributed in 1932. It is generally adapted to the northern and

central states where bacterial wilt is not a factor in stand survival. Yield data from three plantings are presented in Table 3 and elsewhere (7, 8).

TABLE 3.—*Comparative yields in tons per acre of Meeker Baltic compared with other standard varieties at Fort Collins, Colo., for the period 1930–36.*

Variety	3-year average, 1930–32	4-year average, 1931–34	3-year average, 1934–36
Meeker Baltic	5.45	5.41	5.97
Grimm	5.28	5.24	5.42
Hardistan	—	5.33	5.59
Cossack	4.96	—	5.77

LITERATURE CITED

1. GRANDFIELD, C. O. Report of the Kansas State Board of Agriculture. Pages 92–101. 1941.
2. ———. Buffalo alfalfa. Kans. Agr. Exp. Sta. Circ. 226. 1945.
3. ROBERTSON, D. W., WEIHING, R. M., and COLEMAN, O. H. Alfalfa in Colorado. Colo. Agr. Exp. Sta. Bul. 450. 1938.
4. TYSDAL, H. M. The history and performance of the new alfalfa strain, A136. Crop Imp. Assoc., 21st and 22nd Ann. Rpt., 44–52. 1940.
5. ———. Report of action taken by the Alfalfa Improvement Conference and the status of A136 alfalfa. Int. Crop Imp. Assoc., 24th and 25th Ann. Rpt., 36–38. 1943.
6. ———. Description of Ranger alfalfa. U.S.D.A. unnumbered mimeograph publication. 1943.
7. ———. Reports of the Uniform Alfalfa Nurseries. U.S.D.A. 1942–43.
8. WESTOVER, H. L., and TYSDAL, H. M. Reports of the Uniform Alfalfa Nurseries. U.S.D.A. unnumbered mimeograph publications. 1937–41.
9. WILLARD, C. J., and THATCHER, L. E. What alfalfa for Ohio in 1945? Ohio Agr. Exp. Sta. Bul. 231:261–265. 1944.

REGISTRATION OF VARIETIES AND STRAINS OF GRASSES, I[1]

E. A. Hollowell[2]

THE breeding and improvement of grasses in the United States received little attention previous to 1930 with the exception of selection work with some grasses such as timothy, orchard grass, meadow fescue, and reed canary grass. Previous to 1930 most of the grass research work was directed chiefly to problems of culture and management. Organized and intensive grass breeding programs with both cultivated and native grasses were started in 1935 with the inauguration of cooperative programs between many state experiment stations and the Bureau of Plant Industry, U. S. Dept. of Agriculture.

More than 70 different cultivated, introduced, and native grass species are included in this work. Difference in latitudinal adaptation within many species of both cultivated and native grasses has occurred as a result of natural selection. Most of the grasses are cross pollinated and wide variations occur within the different species which offer opportunities for development of superior strains either by selection or hybridization.

In 1941 cooperative Uniform Grass Nurseries were started to determine the regional adaptation and to evaluate the superior qualities of the more promising strains previous to general distribution. Sixty-six nurseries were established in 41 states, most of which were located at state and federal experiment stations.

Enough progress has now been made in the development of superior strains to demonstrate the need for giving attention to methods of increasing and maintaining the genetic purity of new varieties as they become available for commercial use. Since the seed or plant characters of improved strains may not be different in appearance from commercial seed or plants, the need for seed certification is evident, requiring integrated work between grass breeder, crop improvement associations, seed producer and dealer to insure the maintenance and distribution of the superior varieties.

ALTA FECSUE, REG. NO. 1

Alta fescue, a variety of tall fescue, *Festuca elatior* L. var. *arundinacea* (Schreb.) Wimm., originated as a plant selection in 1923. The selection was made from a 4-year-old planting of tall fescue

[1]Registered under a cooperative agreement between the Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture, and the American Society of Agronomy. Received for publication May 26, 1945.

[2]Senior Agronomist, Division of Forage Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture. Member of 1944–45 committee on Varietal Standardization and Registration charged with the registration of grass varieties.
Acknowledgment is made to M. A. Hein, Division of Forage Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture, for the preparation of the introductory statement.

by H. A. Schoth of the Division of Forage Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering, U. S. Dept. of Agriculture at Corvallis, Ore., in cooperation with the Oregon Agricultural Experiment Station. This variety was first distributed in 1934 and has been tested for 15 years. Alta fescue is a long-lived perennial, and when compared with common meadow fescue, a short-lived perennial, is found to have broader and coarser leaves, to be a heavier forage producer, and to be more resistant to both cold and summer drought, as it produces good growth throughout the summer months. It is a bunch grass, making heavy basal leaf growth. The seed of Alta fescue may be distinguished by close examination from common meadow fescue. Alta was first described in 1937.[3] It is adapted to the Pacific northwestern states and has been successfully used for forage and turf purposes in the midwestern and northeastern states. Yield data comparing Alta fescue with commercial meadow fescue are presented in Table 1.

TABLE 1.—*Comparative hay yields in tons per acre of Alta fescue compared with commercial meadow fescue at several places.**

Variety	Oregon		Washington		Minnesota		Montana 1942	Tennessee 1942	Pennsylvania 1943
	1942	1943	1942	1943	1942	1943			
Alta fescue...	3.78	3.54	2.37	1.06	3.67	2.69	1.88	2.30	1.88
Commercial meadow fescue.....	2.08	1.74	2.15	0.51	2.99	2.18	1.05	1.30	2.20

*From unpublished data supplied by cooperating state agricultural experiment stations. The seedings were made in 1941, except those in Pennsylvania which were made in 1942.

Alta fescue, in addition to its superiority over commercial meadow fescue for forage purposes, has shown considerable promise for turf purposes in airport tests in Missouri and the Pacific Northwest. This strain forms a tough, durable vegetative cover that has persisted for 3 years, making an ideal grass to use in combination with redtop and ryegrass. Approximately 500,000 pounds of seed of Alta fescue were produced in 1944.

[3]VINALL, H. N., and HEIN, M. A. Breeding miscellaneous grasses. U. S. D. A. Yearbook of Agr., 1937:1053. 1937.

NOTES

PLANTING WINTER WHEAT AND RYE IN UNPLOWED STUBBLE[1]

WORKERS in the winter wheat regions of the United States will be interested in the discussion of the problem of winter crops by Academician Trofim Lysenko.

He begins his discussion thus, "The question of planting winter crops on unplowed stubble in the prairie regions and the open sections of Siberia, Transural, and northern Kazakstan is one of national economic significance.

"Without entering into the essence of the difference between my proposal and the old well known method, I shall enumerate the basic reasons which are commonly given for low yields of crops planted on unplowed stubbles. These reasons are:

"1. During dry summers it is hard to obtain germination of winter crops on poorly plowed fallow. It therefore follows that for crops planted in stubbles, (that is, in fields which are not worked at all after the harvest) there would certainly be poor germination. On such plantings germination can be obtained only in years with ample rainfall during the latter half of summer.

"2. Winter wheat in the prairie regions of Siberia seldom winters well even on well worked and early plowed fallow. Rye comes through well on 'black' early fallow but on late fallow, which is plowed immediately prior to planting, even rye does not winter well. Therefore, planting on fields which are not plowed at all, that is, plantings in stubble would fail even worse.

"3. Plowing to a depth of not less than 20 centimeters (about 8 inches) safeguards the field from infestation by weeds. Shallow plowing on the other hand causes serious infestation. Therefore, crops planted in unplowed stubble would be infested even more.

"4. During dry summers, winter crops often suffer from lack of moisture even when planted on good black early fallow. It therefore follows that during dry years crops planted in stubbles will die out all together. This because the moisture on such fields was not only not allowed to accumulate but on the contrary was being exhausted by the preceding crops.

"5. Plants feed on minerals. For proper activity of the microorganisms which mineralize organic substances it is necessary to have air in the soil. In the absence of air there will be no plant food and the plants will starve. Working over the soil produces favorable conditions for the access of air. From this it can be concluded that crops in stubbles will certainly starve. On such fields the plants will be small and will produce inferior grain.

"All the explanations brought forth above are, as far as I know, widely accepted among workers in agricultural science.

[1]Excerpts from translation of "What is the Essence of Our Proposal Regarding Planting Winter Crops in Stubble in the Steppes of Siberia" by Acad. T. Lysenko, Sotzialisticheskoe Khoziaistvo, 5-6: 25-36. 1944. The magazine "Sotzialisticheskoe Khoziaistvo" is the official organ of the Narkomzen (Department of Agriculture of the U.S.S.R.).

"Until the fall of 1941, I did not doubt a single one of the accepted explanations of low yields obtained from crops planted on unplowed stubble. However, in the winter of 1941 and spring of 1942 my observations of winter conditions in open unprotected fields lead me to a firm conviction that in the Siberian prairies planting on fallow does not present the best conditions for wintering of crops.

"Winter wheat on fallow seldom makes a crop in the Siberian prairies because it is as a rule winter killed. Rye if sown at the proper time on good fallow fields will stand the winter but even rye winters poorly or does not come through at all when sown in fields plowed too late. A number of detailed observations led me to suppose that in open sections of Siberia the best winter conditions are assured when winter crops are planted *not in fallow but in unplowed stubble.* At the same time the study of winter conditions in Siberia led to the conclusion that the favorable winter conditions which exist on fields in stubble can not be produced on large fallow fields.

"By the spring and summer of 1943 it became obvious that the results of the experimental seedings of winter wheat in stubble carried out under my direction on the fields of the Siberian Experimental Institute for Cereal Crops as well as the data on yields obtained from trial seedings on several state farms exceeded our expectations. Seedings of the more frost resistant kinds of winter wheat on good fallow fields without snow arresters were entirely lost, which is as should be expected. The highly frost resistant rye (Omka) which was planted in September was either badly affected or entirely killed. At the same time plantings in stubbles of all types of winter wheat, the majority of which were of the Odessa and Crimean types, which are of low frost resisting quality, all came through the winter in excellent condition. Furthermore, on the field of the Tcheliabinsk station and at Omsk even sprouts of spring wheat wintered over satisfactorily."

From the results of the experiments Acad. Lysenko concludes that planting in unplowed stubble is effective in preventing winter killing. He points out that the winter of 1942–43 was severe and analyzes the results as follows:

"Observations of the growth of plants and data on yields of plantings in stubble have shown something that we did not suspect when the experiments were started. The results demonstrated that the old commonly accepted explanation of low yields of rye planted in unplowed stubbles in Siberia were not at all valid. Planting in stubbles has always been done by the broadcase method. In spite of multiple harrowing, the rye seed was worked into the soil very poorly. The seeds of weeds which require only shallow depth were worked in much better with the harrow than were the seeds of rye. As a result such broadcast seedings came up too late in the fall. This was especially true under conditions of drought. In the spring and summer of the following year the rye was crowded out by weeds. The horsedrawn drills were inadequate for working the rye seed into the soil. It is only with tractor drawn drills that rye can be well worked into the soil. With this method the seeds of weeds which lie on the surface of the ground

remain in an unfavorable condition. Such in-stubble seedings in the prairies of Siberia not only of winter wheat but also of rye can, as the experiment showed, give yields not lower and in general even higher than the yields of crops sown on fallow and certainly much higher than the entirely unsuitable seedings of rye on fields freshly plowed in September, a practice which unfortunately has recently been widely followed in Siberia.

"Our proposition is that in the prairie regions of Siberia the planting of winter crops should be carried on in the stubble of spring crops which in turn were planted on fallow or sod. Winter wheat must be planted in the last third of August and not later than the first of September. Rye must not be planted later than between the 5th and 10th of September. The crop must be drilled with an adequate tractor drawn disk drill by the crisscross method. Under Siberian conditions with the great range in day and night temperatures at the end of August and the middle of September the heavy dew makes possible a stand even with the small amount of precipitation. Crops put in late, that is, in September and especially late in September can not give a stand even if the crop is put in with tractor drawn drills and even with good moisture conditions, this because of the low temperature.

". . . . Both science and experience have unquestionably proven that shallow plowing causes weed infestation. It would naturally appear at first glance that planting of winter crops in unplowed stubble carried on by the method which I propose would cause greater infestation by weeds.

"In my opinion good stubble seedings of winter wheat and especially of rye made by the proposed method are not only not causing infestation but to some extent appear to be clearing fields from a number of weeds. This does not mean, however, that planting in stubble should be carried out on infested fields. Infested fields must be cleaned out by clean fallow. In 1942 an area of 50 hectars of spring wheat on the Tcheliabinsk station was badly infested with "ovsiug" (wild oats). After the harvest the surface of the soil was thickly covered with the seed of this weed. The number of seeds of the weed reached several thousand per square meter. At the end of August, Miss A. T. Korshumova planted winter wheat on 12 of the 50 hectars of unplowed stubble. The planting was done with a tractor drawn disk by the crisscross method. The remaining 38 hectars were set aside for planting of spring wheat in the spring of 1943. This area (38 hectars) was harrowed late in the fall in order to work in the seed of the weeds thus inducing their germination early in the spring before plowing. At the end of April 1943 this field was covered with a stand of "ovsiug". In May, this land was plowed deeply and planted to spring wheat. This crop of spring wheat was seriously infested by the weeds which grew from seeds remaining on the field prior to the spring plowing. The seeding of winter wheat planted on stubble without any plowing whatsoever (12 hectars) remained practically clean. The "ovsiug" seeds were not worked into the soil when the winter wheat was drilled. They remained on the surface and in the spring and summer after many rains, grew under a heavy cover of

wheat. On each square meter one could easily see hundreds of plants of this weed in the lower layer under the canopy of wheat. These plants, however, were so dwarfed and retarded that they could not head out. On bare spots where there were no plants of winter wheat the weed developed beautifully. It therefore appears that planting of winter wheat in stubble with tractor drawn drills does not cause infestation.

"Results of one, two, three or even more individual experiments cannot settle this important question of weed infestation unless they can be satisfactorily explained by basic underlying principles. I am therefore going to present a theoretical analysis of the question. Weeds as a rule are biologically suited to the same conditions as are cultivated plants. Under conditions of cultivation weeds seldom survive, not because conditions are not suitable but because they are being destroyed at the proper time. When infested fields are left idle the majority of weeds do not increase in number but actually decrease, although nothing is done to destroy them. A good stand of perennial grasses occupying a field for one or two years without tillage does not infest the fields with weeds. On the other hand any crop planted on shallow plowed fields for one or two years is always infested.

"Now if a good stand of perennial grass, rye grass, for instance, remains free of weeds after two or three years, then it follows that a good stand of rye or winter wheat such as can easily be obtained by planting in stubble with tractor drawn drills will also not be infested."

After disposing of the question of weeds the author discusses winter crops planted in accordance with his method in relation to droughts. He reports the following results:

"Experimental plantings of winter wheat in stubble on the fields of the Siberian Cereal Institute at Omsk had shown clearly that such plantings give not only good germination during years with dry late summers but can also better withstand droughts during the growing season. On the fields of the above mentioned institute the very dry late summer of 1942 was followed by an extremely light snowfall in the winter of 1942–43. From November to the first of April the total precipitation amounted to only 15 mm.—0.59 inch. Neither was their ample rainfall during the summer of 1943. Under these conditions winter wheat planted on fallow in open prairies without snow arresters was completely lost during the winter period. On a small field of about 0.6 hectar a heavy snow cover was obtained by means of snow arresters. The wheat on this field was well preserved. One would think that on this field there should have been a good deal of moisture the following spring and summer, however during the summer the plants definitely suffered because of lack of moisture in the soil and the yield was small (8.5 centner per hectar—about 340 lb. per acre). This in spite of the fact that the field was fertilized and was kept in good condition while in fallow. An experimental planting of winter wheat in oat stubble on an adjoining field of about two hectars suffered much less from the drought than the plantings on the fallow fields discussed above in spite of the fact that the soil was thoroughly dried out by the preceding crop (oats)

and the fact that the snow cover during the winter did not exceed 10 to 15 centimeters (4 to 6 inches). The yield of wheat on this field was 9.9 centners per hectar against 8.5 on the fallow. On the fields of the Tcheliabinsk station the precipitation was above normal both in the fall of 1942 and during the growing season of 1943. The yields of crops planted in stubble were accordingly higher than those at Omsk where drought conditions prevailed. The yield of winter wheat in oat stubble on 11 heactars was 18.4 centners per hectar. Winter wheat planted on spring wheat stubble on a very poor field (heavily infested) yielded 10.2 centners per hectar. Similar plantings on a field of 0.63 hectar in spring wheat stubble which followed virgin sod gave a yield of 21.3 centners per hectar. This last cited case corresponds exactly to what we are advocating, namely that *plantings in stubble are best if put in on stubble of spring wheat which was preceded by a good fallow or a sod of perennial grasses.* The average yield of winter wheat in stubble on all fields of the Tcheliabinsk station, a total area of 23.6 hectars, was 14.3 centners per hectar. The average yield of the 39.7 hectars planted on properly tilled fallow was 6.4 centners per hectar (part of the 39.7 hectars was manured at the rate of 40 tons per hectar).

"On the Karagadinsk state farm a large area (several hundred hectars) was planted to winter wheat in stubble in accordance with our recommendations. The planting was done at the proper time. In all cases the yields were as good as those obtained from winter wheat on fallow fields on which snow arresting was carried out during the winter. Similar in-stubble planting of rye gave yields which were not lower than those obtained on fallow. One must remember that the fields of the state farm are located in a region where the growing season is dry and winters are severe."

Lysenko outlines the following procedure for putting his findings into practice. "We propose to begin with the use of winter rye instead of winter wheat in the rotation. Later the rotation should include both winter wheat and winter rye planted in stubble. The proportion of winter wheat and rye cannot yet be determined. In two or three years, experience will show how much of either should be planted.

". . . In following our scheme five fields would be put in grain. Of these, two would be in spring wheat (one in fallow and one in broken sod), two fields would be used for winter crops in stubble and one for spring crops such as oats. This would fit into an 8 field rotation with two fields in grass or into a 9 field rotation with three fields in grass. With such a system the volume of work involved in plowing will be cut exactly in half, which will constitute a major relief in the intensely serious power situation. It is our deep conviction that this method will in the near future find wide application in the prairie regions of Siberia as a means of obtaining a cheaper supply of winter rye and at the same time improving fertility of the soil. This method of planting will be a useful means for combating soil erosion which for a number of reasons is an item of outstanding importance. Finally, the method which we propose makes it possible not only to prevent the loss by winter killing of a large proportion

of frost resistant rye but also opens up wide possibilities for winter wheat."

In the last paragraph Lysenko warns against misapplication of his method. He states "I want to emphasize that our proposition applies only to prairie and open timber prairie regions of Siberia, Tansural and Northern Kazakstan. We do not recommend planting of winter crops in stubble in other regions neither do we recommend plantings in stubble on fields surrounded by forests and therefore protected from wind. On such fields winter wheat and rye may be lost from parasites and diseases during abnormally warm winters and when snow occur too early in the season. I witnessed such losses on such fields in the spring of this year on the Tcheliabinsk station. In such a warm winter similar losses are possible in other places on fields protected by forests."—D. B. KRIMGOLD, *Soil Conservation Service, U. S. Dept. of Agriculture, Washington, D. C.*

TAXONOMIC BOTANY IN AN AGRONOMIC JOURNAL

I WAS both surprised and sorry to find in the April issue of the JOURNAL the paper entitled "*Agropyron japonicum*, an Untenable Name". There are many journals for the publication of taxonomic papers and Mr. Beetle is a contributor to some of them.

The paper noted is wholly taxonomic, not agronomic, and publishes new combinations in Latin names of grasses, which should have no place in an agronomic journal.

Even if we agree that the taxonomic discussion of one introduced grass, which constitutes most of the paper, was proper in a journal of agronomy, these published nomenclatorial changes apply, not to the grass discussed, but to a wholly different Japanese grass of no concern or importance to American agronomists.

There is given no proof, but merely an assumption, that Tracy's name, admittedly erroneous, actually is valid under the rules of botanical nomenclature. If it is not valid, the changes made merely add two more to the existing hundreds of thousands of useless, expensive, and cumbersome synonyms which clutter systematic botany. The quoted agronomic description certainly is not an adequate botanical description, in any sense.

There has been developed a new and wholly unproductive profession, that of synonymy. In it, one group of workers makes myriad new species or new combinations in the Latin names of plants, their names appearing eternally thereafter as the sponsors of the new combinations. Another group, trying to classify plants, spends untold years and uncounted money in trying to determine whether these changes have any basis in fact. Their only reward, oftentimes, is the discovery of unwelcome truth. Should our JOURNAL help to augment what has become an unholy mess?

The taxonomy of plants is the proper activity of many botanical institutions and agencies. Most of them do not maintain files of agronomic journals. Shall we do a double disservice by inflicting taxonomic studies on agronomic subscribers and compelling our colleagues in systematic botany to dig up agronomic journals in order to find taxonomic changes?

I discuss these problems from long experience in both agronomy and botany, and in editing journals. I have been an active agronomist and member and officer of our agronomic society throughout most of my career. I have been editor and/or on the editorial Board of our JOURNAL, of *Plant Physiology*, and of *Biological Abstracts*, for nearly 30 years. In botany, I have published many new species, varieties, and combinations in *Salix* during this long period, but always in botanical journals. Let's be fair both to our members and to our colleagues in taxonomy.—CARLETON R. BALL, *Extension Service, U. S. Dept. of Agriculture, Washington, D. C.*

A METHOD FOR ESTIMATING THE WEIGHT OF ROOTS OF GREEN MANURE CROPS

THE difficulties involved in securing the weight of roots of green manure crops are recognized by investigators of this type of research. The necessity of the inclusion of these data in a correct interpretation of the effects of green manure crops is also recognized, although in some case results are still published in which comparisons of various crops for green manuring are evaluated from the top growth alone, a procedure that could easily lead to inaccurate conclusions.

The usual procedure in obtaining root weights is to wash out the roots from a small measured area, usually from 2 to 4 square feet, with water, dry the roots, and calculate the weight per acre on these small areas. The amount of labor involved from a practical standpoint seriously limits the number or size of the harvested areas which in turn is reflected in the accuracy of the yield data.

The plan suggested here provides a rapid and reliable means of obtaining the yield of roots with a minimum expenditure of time and labor. The plan has as a basis the ratio of the top and root growth. The procedure is as follows:

1. Obtain the yield of the top growth by cutting out areas with suitable equipment. A mower, hedge shears, hand sickle, or scythe may be used, depending on the type of experiment, the condition of the ground, and the previous preparation of the seedbed, if any, for the green manure crop. A small garden tractor equipped with a mower cutting bar is ideal for obtaining yields of tops if the surface of the ground is smooth enough for its operation.

2. Carefully remove a number of entire plants, including the root system, from various portions of the plot so that a representative sample is obtained.

3. Carefully wash out the roots from this sample, dry, and calculate the root-top ratio. The yield of roots[1] is then obtained by multiplying the weight of the tops from the harvested area by this root-top ratio. The sample of roots and tops used for calculating this ratio can then be used for chemical analyses if so desired.

The accuracy of the method depends on the care taken in securing an adequate and representative sample for obtaining the top and root relationship. A relatively large block of soil can be removed and

[1]The weight of roots referred to actually includes the crowns of the plant and a small portion of the tops that is not removed in obtaining the yield of the tops.

actually transferred to the laboratory for careful washing of the roots. Quite often during the spring season a stream with running water serves as a good source of water for washing out the roots. Plants near the edges of the block of soil should be discarded if any portion of the roots and tops are missing.

Three distinct advantages are evident from the use of this method. First, the yield data can be based on a much larger area; second, a representative sample of both tops and roots is secured for chemical analyses; third, the saving in time and labor is enormous. For example, in order to obtain the roots from a 4 square foot area to a depth of 1 foot, 4 cubic feet of soil have to be worked over. This procedure entails the handling of approximately 325 pounds of soil (oven-dry basis). The feasibility, then, of using a method in which this laborious task is largely eliminated and at the same time basing the yield determination on a much larger sample becomes increasingly apparent.—JOHN F. DAVIS, *New York State Agricultural Experiment Station, Geneva, N. Y.*

BOOK REVIEWS

THE CHEMICAL FORMULARY

H. Bennett, Editor-in-chief. Brooklyn: Chemical Pub. Co. Vol. VII, XXXII + 474 pages. 1945. $6.

THIS volume adds 2,500 new formulas to those already printed in volumes I–VI, inclusive. An increasing (and justified) attempt of simplification for the benefit of nontechnical users is apparent. Unfortunately, the very useful introductory chapter of 16 pages has been reprinted practically unchanged from volume VI. The reviewer hoped that in volume VII this most educational approach would be extended for those who own the previous collections. The list of "Sellers of chemicals and supplies" loses much of its value on account of its exclusiveness: One source of supply is named only for every commodity, a hardly justifiable practice. Several names are mentioned in one instance for laboratory equipment, but even here the names of Arthur H. Thomas Co. and the Will Corporation are missing.

The editor puts increased emphasis on farm and garden specialties and food products, the number of pages devoted to these topics having been doubled. This makes the volume of increased usefulness for those engaged in agricultural research. The list of substitutes has been omitted.

The *Chemical Formulary* is by now an institution and an important help to technical schools, to the small manufacturer, to the agriculturist, and to the laboratory worker. A very thorough index greatly increases the usefulness of the volume.—Z. I. KERTESZ.

LABORATORY EXERCISES, BIOLOGY OF PLANTS

By H. L. Dean. Dubuque, Iowa: Wm. C. Brown Company. Planograph, 244 pages, illus. with diagrams. 1944. $1.75.

THIS is a conservative laboratory manual designed for a general elementary course in botany. Apparently the course is to be administered without the use of an assigned textbook but with reference reading from several standard texts and specialized material. The excellent lists of references for each topic constitute one of the best features of the volume.

The main topics emphasized in the manual are as follows: The plant cell, mitosis, the external and internal anatomical features of the leaf, stem, root, flower, fruits, seeds, and seedlings. The physiological processes normally associated with the leaf, stem, and root are considered in connection with the morphological and anatomical treatment of those organs. Reproduction of the angiosperms is considered in connection with the flower. The plant groups consisting of the algae, bacteria, fungi, bryophytes, pteridophytes, and conifers are briefly treated.

The material of this manual is expanded beyond that of the ordinary botany course by the inclusion of material on drug plants, economic plant geography, landscape gardening, Mendelism, practical plant and animal breeding, and plant propagation. The manual is illustrated throughout with good conventionalized diagrams and diagrammatic line drawings.

Special features of the manual are the keys for the identification of the common trees of Iowa, the various kinds of starch grains, common temperate zone woods, the common ferns of Iowa, and the coniferous plants of Iowa.—J. BEN HILL.

NATURAL PRINCIPLES OF LAND USE

By Edward H. Graham. New York: Oxford University Press. XIII 274 pages, illus. 1944. $3.50.

THIS book is chiefly an effort to encourage a greater application of the biological sciences in the solution of wildlife management problems. To this end the author has drawn freely from the literature of ecology, botany, and zoology to cite examples of the value of the natural principles of plant and animal sciences to the natural scientist and sportsman. This book is not a factual book, however, in the sense of a reference book for teachers and scientists, for the author apparently intended to reach a wide and diverse audience, including laymen, conservationists, and sportsmen.

In urging a greater adoption of the principles of the biological sciences in the solution of land-management problems, the author does not give, in the reviewer's opinion, sufficient credit through references and quotations to those agronomists who have for these many years drawn heavily from, as well as contributed to, the biological sciences in the improvement of crop varieties, in the management of the soil through crop rotations, and in the improvement of the soil through the addition of lime and fertilizers.

The author emphasizes the necessity of a classification of land which subject is not handled with the ease and competence with which the author treats the subject matter and principles of ecology. The author correctly stresses the need for classifying land on the basis of its natural characteristics. It is difficult for this reviewer therefore to evaluate the purposes of the author in developing a system of classification which unduly emphasizes subjective criteria. The author suggests further that by classifying the land into eight classes, a basis is provided to land operators for actual practice on specific parcels or units of land. Obviously, class II land in Florida and South Dakota are entirely distinct as regards natural characteristics and therefore must be treated and managed differently. The agronomist, it seems to this reviewer, must be very critical of the system of land classification advocated by the author.

Complete confidence in the proposed system of land classification is apparently lacking, for the author gives a brief but apt discussion of "soil", and emphasizes the need for a study of the soil—its physical, biological, and chemical properties, as these are important in the growth of crop plants. Profiles of several Great Soil Groups—Podzol, Chernozem, and Red Desert—are illustrated, and a brief but carefully selected discussion attests to the acquaintanceship of the author with the fundamentals of soil formation. This reviewer believes that most soil scientists interested in land classification would have encouraged more attention to soil type as a basis for land management and soil management practices.

This book contains many excellent photographs well chosen and adeptly arranged.

This reviewer, while disagreeing with the author on many points, recommends the book for the agronomist to read in more casual moments, and believes the reader cannot fail to absorb some of the author's enthusiasm for the scientific approach to a better use and management of our land.—FRANK RIECKEN.

AGRONOMIC AFFAIRS

HANDBOOK OF DESCRIPTION OF SPECIALIZED FIELDS IN AGRONOMY AND SOIL SCIENCE[1]

FOREWORD

A COMMITTEE of the American Society of Agronomy assisted the National Roster[2] in preparing these descriptions of specialized fields in agronomy and soil science. The time was short, and it was not possible to discuss the many problems with a large percentage of the agronomists and soil scientists of the country, although a few reviewed the early drafts. The final result contains a number of obvious compromises between different points of view.

Perhaps the greatest difficulty centers around the exact meaning of "agronomy." Some feel that this term should be used to include all, or nearly all, soil science as well as crop science, while others confine the term to the applied aspects of the plant sciences as they relate to field crop improvement and production. Since the general field of soil science includes a large body of fundamental soil science that is no more specifically applied to field crop production than to several other problems, and since there are significant applications to fruit and vegetable production, to forestry, to engineering, to land settlement, and to farm organization, it seemed desirable to use both "agronomy" and "soil science" to include all phases of these fields.

Other difficulties were encountered. Although soil conservation, for example, is covered by the other recognized phases of soil science and agronomy, a separate field was recognized because of the recent interest in this subject. This is not entirely logical since the field does not include anything specific that is not included under other headings; yet at the same time, it does not seem appropriate to omit the heading. In agronomy (crop science) some difficulty was had with reconciling functional breakdowns according to broad problems of production and improvement with commodity breakdowns according to crops or groups of crops and with regional specialization. Examples can easily be found where agronomists should be specialized according to any one of these three kinds of divisions.

It was also difficult to find an entirely satisfactory border line between agronomy and horticulture since the division is not made uniformly among different institutions.

The committee calls attention to these difficulties, not in order to justify the present outline but rather to explain some of its obvious inadequacies. This attempt suggests that the fields are not well defined. Precedents may be found for many alternative outlines. Special emphasis was given by the committee to the recent practices and nomenclature followed by the U. S. Dept. of Agriculture, the

[1]Prepared by the National Roster of Scientific and Specialized Personnel, Bureau of Placement, War Manpower Commission.

[2]Dr. Robert Shosteck, Assistant Chief of Placement, had charge of this phase of work for the National Roster of which Dr. George W. Works is Director. Mimeographed copies of the Handbook, published herewith, may be obtained from the National Roster, War Manpower Commission, Washington 25, D. C.

U. S. Civil Service Commission, and the more highly organized universities, especially those granting the Ph.D. degree in these fields. Also, the special precedents and needs of the Roster had to be considered. But the final result is not exactly like any one.

Because this matter of definition and nomenclature is one of considerable importance to individual agronomists and soil scientists in their relationships with one another and with the public, the committee feels that this outline should be drawn to their attention and receive the widest possible study and criticism. Since these professional fields are young and growing rapidly, changes are inevitable and older precedents may be expected to lose their validity. Increasing specialization along functional, commodity, and regional lines may be expected. As in other fields, no perfect classification can be developed but, through wide discussion and criticism, perhaps a system of classification can be arrived at for the future that will serve the profession more adequately than the one developed by this committee.

It is from this point of view that the committee welcomes the opportunity to have its product published and widely criticized by professional workers in these fields.

H. M. Tysdal, *Chairman*
L. T. Alexander C. R. Enlow
B. B. Bayles Charles E. Kellogg

CLASSIFICATION OF AGRONOMY AND SOIL SCIENCE

SOIL SCIENCE (12.4.69)

12.4.00—Soil fertility and management
12.4.10—Soil conservation
12.4.20—Soil genesis, classification and mapping
12.4.30—Soil physics and mechanics
12.4.40—Soil microbiology
40.9.01—Soil chemistry and mineralogy
12.4.55—Soil technology
12.4.65—Other, as tropical soils, forest soils, soil appraisal, etc.

CROP SCIENCE

Crop Production (12.5.59)
12.5.10—Cereal crops and flax
12.5.15—Leguminous crops
12.5.20—Forage crops, other than legumes
12.5.30—Cotton
12.5.35—Sugar cane
12.5.60—Sugar beet and other root crops
12.5.45—Tobacco
12.5.55—Other crops
Crop Improvement (12.6.49)
12.6.00—Corn
12.6.10—Cereal crops, other, and flax
12.6.15—Leguminous crops
12.6.20—Forage crops, other than legumes
12.6.30—Cotton
12.6.35—Sugar cane
12.6.50—Sugar beets and other root crops
12.6.55—Tobacco
12.6.45—Other crops

AGRONOMIC SPECIALTIES, n.e.c.

12.7.00—Turf and other special grass culture
12.7.10—Weed control
12.7.20—Farm planning
12.7.30—Seed production
12.7.40—Crop rotation and cultural practices
12.7.50—Irrigation practices
12.7.60—Grazing management

INTRODUCTION

I. WHAT IT IS

This handbook of descriptions of the specialized fields of work in agronomy and soil science, is one of a series of handbooks being prepared by the National Roster of Scientific and Specialized Personnel. It contains the descriptions of the usual or typical activities of technical personnel working in each of the fields of specialization in agronomy, soil science, and crop science.

The general classification scheme used in this description is a modification of that originally developed by the National Roster during 1940 and 1941, in collaboration with national professional societies. The classification is primarily along crop lines, since most agronomists, soil scientists or crop scientists characteristically specialize along such lines.

The term "fields of specialization" as used in this handbook refers to a well-defined occupational area within the profession. It is the particular type of work performed by a substantial number of agronomists. The work of those classified in any specialization has a number of readily recognizable common elements. These elements include the basic technical knowledge and skills, the particular problems or crops dealt with, and procedures, equipment and operations employed in obtaining the data or results. The various positions which would be classified in this specialty have so many of these elements in common that there is a high degree of transferability among them.

The description is in terms of (a) what the agronomist or soil scientist does (activities, as research, and the subjects of his work, as the crop and the problems of crop improvement, production, or soils dealt with), (b) how he does his work, as the investigations or research he carries on, and (c) why he does it, or the objectives toward which he strives.

Allied fields are also discussed, and the relationships of these branches to other fields of science are pointed out.

The index lists all important crops, techniques, and activities discussed in this handbook.

II. HOW IT WAS PREPARED

This handbook was prepared with the collaboration of officers and a special committee of the American Society of Agronomy. The original draft prepared by the committee was reviewed and revised by other members of the society and by members of the National Roster Staff.

III. HOW IT MAY BE USED

These descriptions were prepared for use of the placement or classification technician concerned with professional personnel. A prior knowledge of most of the basic activities of an agronomist or soil scientist should enable the technician taking a job order to do a much better job of obtaining pertinent and precise information from the employer, and in writing up the request for personnel. Such knowledge should likewise be helpful to the interviewer eliciting job experience information from an applicant or discussing with him employment possibilities.

The technician engaged in coding or classification of applications or registrants on an occupational basis should find this material very useful to him. The index will often serve as a useful key in suggesting possible classifications for types of experience which do not immediately and obviously fall into an established classification.

Particular attention is invited to the practical use of the information on related fields. This information broadens the area for the possible placement of applicants with but one specialized type of experience. It is often the case that there are no

available positions in the specialized field of the applicant, while there may be vacancies in an allied field in which his experience would be valuable.

LIST OF COLLABORATORS IN PREPARATION OF THIS HANDBOOK

A. C. Arny, University of Minnesota, St. Paul, Minnesota
O. T. Bonnett, University of Illinois, Urbana, Illinois
Richard Bradfield, Cornell University, Ithaca, New York
R. J. Garber, U. S. Regional Research Pasture Laboratory, State College, Pa.
H. K. Hayes, University of Minnesota, St. Paul, Minnesota
F. D. Keim, University of Nebraska, Lincoln 1, Nebraska
K. H. Klages, University of Idaho, Moscow, Idaho
J. D. Luckett, New York State Agricultural Experiment Station, Geneva, N. Y.
M. L. Nichols, Soil Conservation Service, Washington 25, D. C.
F. W. Parker, Plant Industry Station, Beltsville, Maryland
W. H. Pierre, Iowa State College, Ames, Iowa
G. G. Pohlman, University of West Virginia, Morgantown, West Virginia
N. J. Volk, Purdue University, LaFayette, Indiana

COMMITTEE OF THE AMERICAN SOCIETY OF AGRONOMY

C. R. Enlow, Soil Conservation Service, Washington 25, D. C.
L. T. Alexander, Division of Soil Chemistry and Physics*
B. B. Bayles, Division Cereal Crops and Diseases*
Charles E. Kellogg, Division Soil Survey*
H. M. Tysdal, *Chairman*, Division Forage Crops and Diseases*

*Plant Industry Station, Washington 25, D. C.

DESCRIPTION OF THE SPECIALIZED FIELDS IN AGRONOMY AND SOIL SCIENCE

(The term "agronomy" is defined by different people and institutions in three principal ways: (1) By some, as all crop science and soil science; (2) by others, as the applied phases of both crop science and soil science as related to field crop production; and (3) by still others, as the applied phases of crop science.)

OCCUPATIONAL SUMMARY

Agronomy, in its broadest meaning, is concerned with the technical aspects of plant, soil and related sciences and their application to field crop production, soil management and improvement, crop improvement and utilization. In many of the land grant colleges, Departments of Agronomy include soil science as well as the crop science of agronomy. The term Agronomist is the usual title given to individuals specializing in this professional field of technical agriculture.

The original distinction between agronomy and horticulture was that the former science dealt with crops grown in the field, while the latter dealt with garden and orchard crops. This distinction no longer prevails, since many of the garden crops, such as lettuce, onions and peas, which today are grown as field crops, are dealt with by the horticulturist. Some agronomists, however, carry out research in a few of these field crops, which traditionally were the concern of the horticulturist.

Soil science is the scientific study of the nature, distribution, origin, use, conservation, and improvement of soils, and the application of scientific principles to their management for plant production and for other purposes.

Agronomy[1] involves the scientific study of field crops as related to their production, breeding, improvement, and utilization. Objectives in such studies are to develop methods for the most efficient production, management and utilization of field crops as well as to improve existing varieties with reference to soil and climatic adaptation, disease and insect pests, and other characteristics leading toward sustained or increased production of high quality products.

Agronomists and soil scientists may specialize along regional lines as well as by crops or by other fields of specialization. Such regional specialization calls for familiarity with the major crops or soil types of the region.

These major fields merge into one another and into related fields, such as horticulture, botany, chemistry, physics, microbiology, plant ecology, plant

[1]In its narrower meaning.

physiology, plant pathology, genetics, forestry, geology, geography, engineering, economics (production and farm management), and other branches of agricultural science. Many specialists may be qualified in more than one subdivision.

FUNCTIONS

An agronomist or a soil scientist may specialize in one or more of the following functions:

1. *Research* through scientific experiments and field surveys into the nature, origin, management, distribution, use, conservation, and improvement of soils; and into crop production, improvement, and utilization. Other studies include flood control and construction as these relate to soils.
3. *Consulting work* regarding soil characteristics in relation to its uses in construction and in planning foundations and subgrades, and for commercial agricultural companies.
5. *Extension* of principles of crop and soil science through demonstration and education, including the planning of demonstration farms and direct assistance to farmers and other land users.
6. *Teaching* in colleges, universities, and technical schools.
7. *Management* of production, sales, service, and distribution of fertilizers, soil amendments, soil inoculants, seeds, etc., also of large-scale plantations, particularly in the tropics.
9. Other:—a) Appraisal of soil productivity and rural land evaluation.
   b) Writing along pertinent technical lines, usually in connection with other functions.
   c) Crop estimates and appraisal of crop damage.

SOIL SCIENCE

The soil scientist[2] is primarily a research worker in field and laboratory, a teacher in colleges, universities and technical schools, and advisor in soil use and manipulation for construction, or an advisor in rural land use and management.
He is concerned with the fundamental principles of soil origin, distribution, composition, chemical properties, behavior, and their application to individual soil management practice, crop production, farming systems, and to those community enterprises that influence the soil or limit the alternative uses of soil.

FIELDS OF SPECIALIZATION

Soil Fertility and Management (12.4.00)

Deals with the application of the principles of agronomy and soil chemistry as developed by scientific experiments and field studies, to the production of crops, and maintenance of soil productivity through the use of fertilizer, lime, composts, manure and other soil amendments, and of cover and green manure crops. He relates the use of these materials to local soil characteristics, to tillage, crop rotations, and other farm practices, and to the requirements of particular crops. Related fields include agricultural chemistry, all soil specialties, plant physiology, agronomy and farm management.

Soil Conservation (12.4.10)

The soil conservationist deals with the application of principles of soil science and agronomy developed by scientific experiments and field studies, to the planning of crop rotations, soil management practices as strip cropping, contour plowing, and land use on the farm unit, reforestation, as these relate to the conservation of soil and water. Related fields include agronomy, agricultural engineering, soil fertility and management, farm management, and soil classification.

Soil Genesis, Classification and Mapping (12.4.20)

Studies by means of field trips, laboratory examination, and controlled experimentation, soil morphology, genesis (processes of soil formation), classification

[2]Occasionally called "pedologist", especially in some European literature.

and productivity; and develops and carries out programs of classifying and mapping soils. He evaluates the response of various soil types to management practices, and the adaptability of various crops to different soils.

Related fields include all soil specialties, crop production, geology, plant ecology, geography, and agricultural economics (production and farm management).

Soil Chemistry and Mineralogy (40.9.01)

The application of principles of chemistry, mineralogy and agronomy to the problems of soil classification, formation, and composition; and soil problems encountered in crop production and soil management. Related fields include soil physics, soil microbiology, soil fertility, soil classification, geology, and plant physiology.

Soil Microbiology (12.2.40)

The application of the principles and methods of microbiology and chemistry to: the studies of microbiological processes; the solving of problems which affect crop production, such as decomposition of organic matter by action of bacteria and fungi, and nitrogen fixation; soil fertility and management; soil and water conservation; soil genesis, morphology and classification; and the production and use of soil inoculants. Related fields include taxonomy of bacteria, physiology of bacteria, mycology, plant chemistry, soil chemistry, biological chemistry, soil fertility and management, soil physics, soil genesis, morphology and classification and crop production.

Soil Physics and Mechanics (12.4.45)

The application of the methods and principles of physics to (a) a solution of soil problems encountered in crop production, soil classification, drainage, and irrigation practices, and soil and water conservation and use; and (b) problems of soil stabilization and drainage for use as foundations for roads, dams, buildings, and other structures. Related fields include soil chemistry, mathematics, mechanical and civil engineering, soil classification, physics, and geology.

Soil Technology (12.4.55)

The application of the principles and methods of soil science, agricultural engineering and associated fields to the development of effective practices in: (a) irrigation and drainage, (b) tillage, (c) runoff and erosion control techniques and structures. Related fields include soil chemistry, soil physics, soil fertility, soil classification, and agricultural engineering.

Other Specialties (12.4.65)

There are several other specialties in soil science which, although important, do not include many individuals at present. In these specialized fields scientists have focused their attention on particular problems or areas such as tropical soils, forest soils, farm planning, and soil productivity appraisal.

AGRONOMY (CROP SCIENCE)

CROP PRODUCTION

SUMMARY

The agronomist, crop scientist, or other specialist working in this field carries out scientific experiments to develop methods for the most efficient production and utilization of field crops. He studies methods of seed bed preparation, suitable plant varieties, botanical relationships, methods of cultivation, soil and fertilizer requirement, time and method of planting, effects of rotation of crops, harvesting and marketing of crops, and control of crop enemies (diseases, insects, animals). To develop such methods he performs experimental work on the response of plants to their environment, such as the effect of temperature, nutrition, rainfall, humidity, length of day, sunlight and storage conditions on quality, quantity, time of ripening, and other characteristics of agronomic crops. He also studies

the effect of soil, drainage, altitude, weeds, and wind on crop plants. He takes into account factors, such as conservation of soil and of its fertility in any crop production program with which he may deal. In these studies he draws upon his knowledge of the fundamental principles of plant physiology, plant pathology, entomology, soil science, and other fields, because they are all involved and interrelated in the growth and production of the crop. It is often to his advantage to be familiar with modern field plot design and statistical analysis of experimental results. The various fields of study listed above can be applied to any one of the following crops and crop groups.

Related fields include soil science, plant pathology, plant physiology, ecology, agricultural economics, botany, bacteriology, horticulture, plant introduction and exploration, agricultural engineering, entomology, and biometry.

FIELDS OF SPECIALIZATION

Cereal Crops (12.5.10)

Deals with any of the activities noted in the summary in connection with the small grains, wheat, oats, barley, rye, and rice, corn, grain sorghum and the oil crop flax, which are the important members of this group.

Leguminous Crops (12.5.15)

Among the more important crops dealt with are alfalfa, clovers, lespedeza, and kudzu for hay, silage and pasture; soybeans and peanuts for forage, seed, and oil; and cover crops such as Austrian winter peas, field beans, vetches, and lupines. Seed production of many of the small seeded legumes presents special problems, and their use in conservation practices is an important phase of crop production.

Forage Crops (other than legume) (12.5.20)

Deals with the hay and pasture crops, which for the most part belong to the grass family, such as Brome grass, crested wheat grass, Orchard grass, and Timothy and Kentucky bluegrass in the north; Bermuda grass, Dallis grass, Bahia grass, Johnson grass and others in the southern states. Some cereal crops as oats, barley, and sorghum and corn, when grown for hay or silage, fall into this group. In addition there are a number of native grasses of great importance in range and livestock production. The best use of these crops in rotation and for soil conservation and animal production constitute important studies.

Cotton (12.5.30)

Deals with most of the activities discussed in the summary and also with other crops grown in rotation with cotton, such as peanuts.

Sugar Cane (12.5.35)

Deals with the problems of crop production under tropical or semi-tropical conditions; with methods of vegetative propagation, and with special problems in planting, culture, and harvesting of the crop.

Sugar Beets and Other Root Crops (12.5.60)

Deals with sugar beets or other root crops such as turnips, mangoes and swedes. When grown as field crops, these are the concern of the agronomist; as garden crops, they are usually dealt with by the horticulturist.

Tobacco (12.5.45)

Deals with many problems peculiar to the crop, such as starting the plants under exacting environmental conditions, and transplanting, harvesting and curing practices; also problems of field production, and use of fertilizers.

Other Specialties (12.5.55)

Such crops as potatoes, sweet potatoes, rubber plants and drug plants, hemp, fiber flax, may be classed as either horticultural or agronomic crops, depending upon the manner and the region in which they are grown.

CROP IMPROVEMENT

SUMMARY

The agronomist, uses various breeding techniques to develop varieties of crops which are much better adapted than those varieties now available for efficient production and utilization. He seeks such improvements as resistance to destructive diseases, insects, drought, winter killing, lodging (falling down due to wind or rain), or some other hazard to crop production, or he tries to develop varieties with different plant or seed characteristics which better meet certain conditions of production or utilization, such as higher yield or better quality. The use of mechanized equipment, for example the combine for harvesting grain sorghum, is often contingent on the development of varieties with plant characteristics different from those previously grown.

Breeding and selection techniques are used in developing better adapted vegetative covers for protecting the land in different regions against destructive erosion. In like manner, plants may be developed with types of root systems which will make the soil more permeable to water, and will help to facilitate drainage. The plant breeder also develops ways and means of utilizing biological phenomena such as hybrid vigor in corn and alfalfa to provide growers with crops that are more productive and less subject to production hazards.

Three methods of breeding are used to improve varieties of crop plants: (1) Introduction and careful testing of new crops and varieties from foreign countries, (2) Selection of improved strains from old varieties, and (3) Hybridization of varieties each of which contains certain desirable inherited characters, and the selection in later generations of strains which combine the desirable characters from both parents.

In the development of new, improved varieties new technics of breeding and of selecting desired types often need to be developed for handling specific breeding problems. The specialist in this field must often undertake technical genetic studies to solve a particular breeding problem.

The specialist must be familiar with the principles of genetics, cytology, and other sciences used in plant breeding, and he must be familiar with the many variations in procedures and techniques connected with the breeding of different crops. Crops which can be propagated vegetatively, often allow a different approach to the breeding problem. The plant breeder should be familiar with modern field plot technic and statistical analysis of experimental results. Related fields include: genetics, plant pathology, entomology, morphology and cytology, cereal chemistry, plant physiology, soil science, ecology, taxonomy, economic botany and biometry.

The various activities of the agronomist in crop breeding work may be carried out in relation to one or more of the crops or crop groups listed below.

FIELDS OF SPECIALIZATION

Corn (12.6.00)

Production of pollen in the tassel and of female flowers in the ear allows corn to be largely cross-fertilized, and makes possible the development of procedures to utilize commercially the phenomena of hybrid vigor in improving this crop. The problem of breeding is one of inbreeding and selection of true breeding lines with the desired inherited qualities, and determining those which when crossed produce hybrids with the desired characteristics. Since hybrid corn is a true hybrid, it does not breed true and new hybrid seed must be produced each year. Corn is especially well suited and is being used widely for genetic work because of its low chromosome number and mode of reproduction.

Cereal Crops (12.6.10)

Deals with breeding of crops which are largely self-fertilized, such as wheat, oats, barley, rice, and sorghum. The specialist breeds productive varieties that are resistant to destructive fungus and allied diseases, to insects, and to environmental hazards; have satisfactory quality of grain, and which mature at or near an optimum date. The appearance of more virle races of diseases such as rusts and smuts complicates the breeding problem and makes it necessary occasionally to breed resistance to new races of diseases into varieties of cereal crops resistant to the races previously known.

Leguminous Crops (12.6.15)

Carries out experiments in the breeding of various leguminous crops for disease resistance, longevity of stand of perennials, physical nature of plant, yield of forage, yield of seed, and quality of crop. Deals with such crops as alfalfa, clovers, and lespedeza, soybeans and peanuts. In the latter two crops the seed content is an important factor in breeding. The methods of breeding vary with the mode of pollination of the crop. Red clover, for example is usually highly self-sterile and requires very different breeding procedures from soybeans, which are largely self-fertilized. Alfalfa is largely cross fertilized and is handled in a still different manner. Specific breeding procedures are worked out for each leguminous crop.

Forage Crops (other than legumes) (12.6.20)

Carries out breeding experiments to improve hay and pasture grasses, and deals with those which are normally cross-fertilized such as brome-grass and crested wheat grasses and those which are more strictly self-fertilized such as slender wheatgrass and many of the annual forage grasses.

Cotton (12.6.30)

Carries out breeding experiments for improved and standardized fiber quality, high yields, resistance to diseases, and to developing varieties that will lend themselves to harvesting by mechanical pickers.

Sugar Cane (12.6.35)

Uses methods outlined in the summary on crop improvement to develop disease-resisting varieties and those which yield more sugar per ton of cane.

Sugar Beets and Other Root Crops (12.6.50)

Uses the principles outlined in the summary on crop improvement to breed for such qualities as higher sugar content of roots or disease resistance. Other root crops dealt with include turnips, mangoes, and swedes.

Tobacco (12.6.55)

The specialist makes use of many varieties and several species of tobacco in breeding for improved varieties, especially for leaf quality which is very difficult to evaluate. He also carries out breeding experiments to develop varieties resistant to diseases, some of which cause serious losses in yield and quality.

AGRONOMIC SPECIALTIES, N.E.C. (12.7.39)

Turf and other Special Grass Culture (12.7.00)

Deals with development of breeding and management methods relating to the seeding and maintenance of fine turf, heavy duty vegetation, grasses that control sand blowing, or tie down the soil on embankments. Develops soil management techniques which can be used to build a soil on which vegetation will grow on excavations, fills, subsoils, and under other adverse conditions. In developing new methods or in making recommendations, he carries out experiments or uses his knowledge of the use of lime, fertilizers and soil amendments, surface mulch and composting, and of soil treatment to effect good drainage, improve the retention of moisture in droughty soils and improve its quality and structure. In this work the agronomist uses his broad knowledge of plants and the adaptability of particular species for different conditions and uses. He develops methods of establishment of a turf, including the time, manner and rates of planting, soil treatments for disease and insect control, and methods of management to maintain vegetation in good condition at all times are highly important.

Noxious Weed Control (12.7.10)

Deals with the development of methods and practices for the control of noxious weeds on farms, banks of irrigation ditches and on public lands, using his knowledge of the growth and seeding habits of weeds and of crops, the effect of chemicals on soils and plants, and the use of smother crops, sod crops, crop rotations and

tillage methods on weed control. He carries out experiments to determine the value of new or inadequately tested weed killing elements or compounds. Assists farmers in planning for the use of their land in a manner that will bring a maximum return and conserve the soil.

Farm Planning (12.7.20)

The specialist uses his knowledge of methods of soil management, and proper land use in planning crop production, and the necessary field arrangement for proper crop rotation. He considers the farm as a unit and plans crop rotations and pastures to take care of field requirements and conserve the soil, and to provide for such cash crops as the farmer may wish to grow. This planning requires a knowledge of soils and of various crop production methods, the use of fertilizers and lime. He uses his knowledge of soil conservation practices, such as strip cropping, contour farming, establishment of pastures, revegetation of eroded areas, and agronomic control measures for terrace outlets, drainageways, and gullies. Thorough familiarity with farm equipment, farm management, and the business side of farming, is important.

Seed Production (12.7.30)

Agronomists are responsible for the technical aspects of seed production, harvesting, storage, processing, and marketing. The production of pure seed, involving seed certification requires use of the principles and practices of plant breeding, especially knowledge of experimental procedures and the design and analysis of field experiments, and the use of production techniques that effectively prevent contamination by weed seeds, cross pollination, and the entry of disease-causing organisms.

Specialists may be responsible for the analysis and testing of seeds for compliance with seed laws regarding non-contamination with weed seeds, disease organisms, or seeds of other varieties, and for quality and vigor of the variety being tested.

Crop Rotation and Cultural Practices (12.7.40)

The agronomist specializing in this field is familiar with both crop and soil science as they are intimately related in necessary studies of the affect of different crops and crop sequences on the soil, and the effect of fertility and soil management on the crop. He must study the economic value of different cropping systems with particular reference to yields and affect on the soil over a period of years. In studying cultural practices he must be prepared to evaluate different methods of soil management together with different times of planting, management, or harvesting of the crop.

Irrigation Practices (12.7.50)

The specialist in irrigation practices uses his knowledge of the requirements of crops for moisture in order to recommend practices that secure high production of crops. He recommends the frequency of applying water and the quantity to apply in order to get crop production without using excess water. He plans the layout of irrigation ditches and laterals, the length of run and the method of water distribution. He plans the application of water so as to cause the least possible soil erosion and to insure that all plants receive an adequate supply without waste. He recommends the use of sod crops in crop rotation in connection with irrigation in order to maintain the proper soil structure and thus help to provide adequate drainage and reduce the need for tile or other drainage. He plans special techniques for crop fertilization under irrigation conditions.

Grazing Management (12.7.60)

Deals with the proper stocking of pastures and ranges to get the greatest production of forage and yet maintain a desirable population of grazing plants. Uses his knowledge of growth habits of both desirable and undesirable plants in order to plan the length of the grazing season and when to reduce or increase the number of grazing animals because of drought, unusual precipitation, seed pro-

duction or for other reasons. Carries out measures for the control or eradication of undesirable vegetation, for the renovation of old pastures, and for the establishment of new pastures. In this connection he uses his knowledge of the value of lime, phosphate, potash, nitrogen, and other fertilizers and soil amendments and their effect on plant population and forage production. He also uses his knowledge of how to establish and manage grasses and legumes in extensive areas, as well as his knowledge of soils, seedbed preparation and time and method seeding.

The grazing management specialist must be familiar with livestock requirements and management. The plans he develops may include a supplemental grazing crop, the establishment of watering places and the distribution of salt in order to get the best utilization of forage and to avoid erosion.

THE 1945 ANNUAL MEETING CANCELLED

IN VIEW of the travel situation and resulting restrictions by the Office of Defense Transportation, the Executive Committee recently voted to cancel the 1945 annual meeting which had been scheduled for November 20 to 22 in Cincinnati, Ohio.

The Executive Committee voted to have new officers elected by a mail ballot. Dr. G. G. Pohlman, Dr. L. D. Baver, and Prof. I. J. Johnson have been appointed as a committee to recommend a procedure for the election by mail. It is expected the ballot will include all regularly elected officers of the American Society of Agronomy and Soil Science Society of America.

Provision has been made for the nomination and selection of Fellows of the Society. This is being handled by Vice President Hughes, Chairman of the Committee on Fellows.

The Executive Committee is endeavoring to arrange for a meeting of (a) the present Executive Committees of the Agronomy and Soil Science Societies, (b) the newly elected officers, and (c) the Committee on Policy and Program. The proposed meeting would be held in November or December and would consider all matters of business and policy of the two societies.

The Executive Committee invite members to correspond with them relative to any matters pertaining to Society affairs.—F. W. PARKER, *President.*

NEWS ITEMS

IT IS REPORTED IN *Science* that a seed storage and processing plant for handling inbred lines and single crosses is being constructed at the University Farm of the Department of Agriculture of the University of Minnesota. The building will be used almost entirely for the handling of inbred lines of corn and single crosses that are used in the hybrid varieties recommended by the Minnesota Experiment Station.

—A—

ACCORDING TO *Science*, Dr. G. J. Bouyoucos, research professor of soils at Michigan State College, has been named an agricultural consultant to the Government of Greece.

DOCTOR EDWARD G. BAYFIELD has resigned as Head of the Department of Milling Industry, Kansas State College, to become Director of Products Control and Research for the Standard Milling Company. His new address is 309 West Jackson Boulevard, Chicago 6, Ill.

—A—

PROFESSOR FRED V. GRAU resigned his position as Extension Agronomist, Pennsylvania State College, effective August 1st, to become Director of the Green Section, U. S. Golf Association.

—A—

DOCTOR H. E. MYERS of the Soils Department, Kansas State College, has returned to his duties at the College following a period of service with the U. S. State Department in agricultural work in Egypt.

—A—

DOCTOR CHARLES E. KELLOGG, Chief of the Division of Soil Survey, U. S. Dept. of Agriculture, was one of a party of 14 American scientists who attended the celebration in Moscow and Leningrad from June 15 to 29 in connection with the 220th anniversary of the Academy of Science of the U. S. S. R., as the guests of the Academy. The trip was made by air from New York to North Africa and Iran to Moscow, and the return across Siberia and Alaska to Washington.

—A—

CHARLES J. BRAND, formerly Executive Secretary of the National Fertilizer Association, was recently elected President of the Agricultural History Society of the United States at the 26th annual meeting of the organization in Washington.

—A—

DOCTOR GILBEART H. COLLINGS, author of the well-known book, "Commercial Fertilizers—Their Sources and Use", has recently organized a private professional fertilizer consulting service for fertilizer manufacturers and dealers. The new organization is known as Collings and Associates, and is located in Clemson, S. C.

—A—

LAMBERT C. ERICKSON, formerly seed analyst for the State of Wyoming, has been appointed Associate in Agronomy at the University of Idaho and placed in charge of a recently organized weed research project. Dr. H. W. E. Larson, for the past 9 years Soil Extension Specialist at the University of Idaho, has accepted a position with the Chemistry Department of the Georgia Agricultural Experiment Station. Mr. Vance Smith has been appointed to the position at the University of Idaho vacated by Doctor Larson.

THE IMPORTANCE OF PEANUTS LEFT IN THE SOIL IN THE INTERPRETATION OF INCREASES IN YIELD DUE TO SULFUR TREATMENTS[1]

ROGER W. BLEDSOE, HENRY C. HARRIS, AND FRED CLARK[2]

SEVERAL workers in various states have reported (2, 5, 6, 7, 9, 12, 17, 18)[3] that the yields of peanuts have been increased by the use of sprays and sulfur dust. Others (4, 16) have pointed out that the results of fertilizer and other experiments with peanuts are frequently inconsistent, with a wide variation in response. Such variation might be due to several factors. For example, any treatment that would influence the date of maturity or diseases of the foliage or pegs probably would have an effect on the amount of nuts produced and left in the soil at harvest. For this reason it is necessary to have complete yield data before the results of a treatment can be properly evaluated. Some preliminary experiments with sulfur treatments of peanuts as related to yields have been conducted at Gainesville, Fla. The purpose of this publication is to give a summary of the results and to use some of them to illustrate how important the peanuts left in the soil during the digging process are to the interpretation of the results.

This report deals with seven experiments conducted during 1944 with a total of 420 plots. The sulfur treatments, with the exception of one experiment, were in conjunction with various fertilizer treatments. Only the effects of sulfur will be discussed in this paper.

OUTLINE OF EXPERIMENTS

EXPERIMENTS 1, 2, AND 3

Florida Runner peanuts were planted April 20 on Norfolk fine sand which had been in peanuts the previous year. Peanuts following peanuts is not a good practice, but that system was a part of the fertility phase of these experiments. The pH value of the soil was 5.6 to 5.8 and a modification of the Morgan (8) rapid soil test indicated that calcium, magnesium, and potash were low and phosphorus between low and medium.

Experiment 1 dealt with 15 fertilizer ratios, experiment 2 with 6 placements of a 2–10–4 fertilizer at 300 pounds per acre, and experiment 3 with 5 combinations of lime, magnesium, and sulfur used in connection with 500 pounds per acre of a 2–16–10 fertilizer.

Sulfur dust (325-mesh) was applied in strips by machinery across the fertilizer plots in the above three experiments. This formed dusted and nondusted sub-blocks composed of four-row plots 12×50 feet. The dust treatment in experiment 1 was duplicated and triplicated in experiments 2 and 3. Sulfur dust was applied in three applications, June 16, June 29, and July 13, at approximately 20 pounds per acre per dusting. The peanuts were harvested September 7 and 8. Lime seemed to hasten maturity and some of the nondusted plots in experiment 3 probably should have been harvested sooner.

[1]Contribution from the Department of Agronomy, Agricultural Experiment Station, University of Florida, Gainesville, Fla. Published with the approval of the Director. Received for publication March 15, 1945.

[2]Associate Agronomist, Associate Agronomist, and Assistant Agronomist, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 694.

EXPERIMENTS 4, 5, AND 6

These experiments were similar to experiments 1, 2, and 3, respectively, except that they were conducted on Arrendonda loamy fine sand which had been idle the previous year. The pH value of the soil was 6.2 and the rapid soil test indicated that calcium was low and magnesium, phosphorus, and potash medium. Dusted and nondusted parts of three-row plots were 9×50 feet. Florida Runner peanuts were planted May 19 and harvested September 25. Plants were dusted June 29, July 13, and July 28, using the same rate and method as above.

EXPERIMENT 7

This study consisted of time, rate, number of applications, and method of applying sulfur to peanuts. The soil was Norfolk fine sand which was not cropped in 1943 and fertilizer was not applied because the soil was thought to be in a productive condition for peanuts. The pH value was 6.2 and rapid soil tests indicated that calcium was low and magnesium, phosphorus, and potash medium. Dixie Runner, a hybrid developed by the Florida Experiment Station and similar to the Florida Runner, was planted in this experiment May 10. The sulfur treatments were replicated in four randomized blocks composed of two-row plots 6×25 feet.

Sulfur dust (325-mesh) was applied in all of the following combinations: 1. Rates: 20, 60 and 100 pounds per acre applied to the soil or on the foliage. 2. Applications: (a) Each of above rates applied to foliage or soil in one application at 38, 62, and 86 days after planting. (b) Each of above rates applied to foliage or soil in three applications beginning 38, 62, and 86 days after planting.

Where dust was applied to the foliage, a cage the size of the plot was used, the sides of which were covered with six thicknesses of cheesecloth to a height of 5 feet to prevent the drifting of sulfur. Dustings were done by shaking on the plants weighed quantities of sulfur through 12 thicknesses of cheesecloth. This method of application probably did not give as thorough distribution as machine dusting which was used in the other six experiments.

Where the sulfur was put on the soil, weighed quantities were mixed with soil from the respective plots to increase bulk and to assure more even distribution. The sulfur treatments were distributed by hand on the soil under the plants when the foliage was dry. Care was exercised to prevent the sulfur from getting on the foliage. This was done to determine whether there might be a difference in the influence of sulfur when applied on the foliage or on the soil.

The sulfur treatments for the 38-, 62-, and 86-day periods were applied June 19, July 13, and August 6, respectively. Where there were three applications of sulfur, the first was applied on the date indicated and the other two at approximately 12-day intervals. In this way treatments continued throughout the summer until September 2. Peanuts were harvested September 25 at which time the nuts were considered to be at the proper stage for digging.

In all experiments the peanuts were harvested with a peanut plow which cut the tap roots of the plants. After curing, the plants were hand stacked according to the custom in the peanut area.

RESULTS

A summary of the effect of the sulfur treatments on the yields of peanuts for the seven experiments is given in Tables 1, 2 and 3. A statistical analysis indicated that only the differences in experiment 3 were significant. In that case the increase in yield due to dusting was 12.8%. Sulfur treatments in experiment 7 had no influence on total yields of peanuts regardless of whether the sulfur was dusted on plants or placed on the soil.

Sulfur dustings this year at Gainesville had little influence on leafspot or total yield of peanuts as contrasted with results reported by other workers (1, 2, 5, 6, 7, 9, 12, 17, 18) where only the peanuts remaining on the vines were considered. Furthermore, unpublished

TABLE 1.—*Total yields in pounds per acre of Florida Runner peanuts harvested and sieved out of the soil of dusted and nondusted sub-blocks of experiments 1, 2 and 3.*

Experiment No.	Treatment	Total yield in pounds per acre from sub-blocks
1	No dust	1,165
	Dusted	1,290
2	No dust	1,285
	Dusted	1,261
3	No dust	1,260
	Dusted	1,422*

*Significant difference at the 5% level.

TABLE 2.—*Yields in pounds per acre of Florida Runner peanuts harvested but not sieved out of the soil of sulfur-dusted and nondusted sub-blocks of experiments 4, 5 and 6.**

Experiment No.	Treatment	Yields in pounds per acre of peanuts from sub-blocks
4	No dust	816
	Dusted	900
5	No dust	737
	Dusted	879
6	No dust	760
	Dusted	818

*Differences were not significant according to the "F" test.

TABLE 3.—*Mean yield in pounds per acre per plot of four replicates of Dixie Runner peanuts harvested and sieved out of the soil when sulfur was applied at different dates and times on the foliage or the soil in experiment 7.**

Amount of sulfur applied per acre, lbs.	No. of appli-cations	Yield in pounds per acre where sulfur was applied number of days indicated after planting					
		38 days		62 days		86 days	
		Dust	On soil	Dust	On soil	Dust	On soil
20	1	1,249	1,133	1,336	1,423	1,365	1,336
60	1	1,307	1,162	1,278	1,481	1,016	1,423
100	1	1,481	1,220	1,510	1,539	1,452	1,394
20	3	1,394	1,278	1,220	987	1,278	1,220
60	3	1,336	1,307	1,394	1,307	1,394	1,394
100	3	1,394	1,394	1,626	1,423	1,510	1,133

Check 1 (no sulfur; mean of 4 values) 1,074 lbs.
Check 2 (no sulfur; mean of 4 values) 1,394 lbs.
Check 3 (no sulfur; mean of 4 values) 1,423 lbs.

*Differences were not significant according to the "F" test.

data of the Florida Agricultural Experiment Station for the past 5 years indicate a 15 to 20% increase in yield of nuts due to sulfur dust when no consideration is given to nuts left in the soil. July and August were damp and rainy in 1944 (Table 4) and conditions seemed favorable for leafspot development. Leafspot was present in all experiments, and when plots in experiment 7 were rated September 12 with the assistance of plant pathologists, results showed no correlation between treatment and disease control that year.

TABLE 4.—*Precipitation in inches at Gainesville, Fla., during the peanut growing season of 1944 as compared to the normal.**

Season	May	June	July	August	September
1944	1.80	3.73	9.32	7.16	2.66
Normal	3.15	6.84	7.34	6.50	5.37

*Climatological Data, Florida Section, Weather Bureau, U. S. Department of Commerce.

Some authors (2, 7) have reported that sulfur dust controls leafhoppers. Although peanut damage from leafhoppers has not been reported on peanuts in Florida, the velvet bean caterpillar, *Anticarsia gemmatilis* (HBN.), frequently causes serious damage. An infestation of that insect was seen August 23, 1944, and one application of 20–80 cryolite dust seemed to give a good control of the worms. It appeared that sulfur acted as a repellent to the moth, for those plots recently dusted were relatively free of worms.

Although peanut hay yields for the experiments are not reported, sulfur gave a statistically significant increase in yield of hay in experiments 3, 4, and 5. It is possible that the increased hay yield of sulfur-dusted plots was partly due to less caterpillar damage. If sulfur delays maturity, an increase in hay yield would be expected in experiment 3 since some of the nondusted plots of that experiment were harvested a little late. It should be noted that sulfur had a significant effect in more experiments on the hay yields than on the nut yields.

PEANUTS LEFT IN THE SOIL

When the peanuts were harvested by the ordinary digging process, it was observed that many were left in the soil on some plots. Because of this the soil of all plots in experiments 1, 2, 3, and 7 was sieved to check the amount of peanuts shed. It was thought that shedding was not a factor in the other experiments. However, the results secured by sieving the above experiments leave that point in doubt. Randomized samples of 20% of each plot in experiment 7 and 10% of each plot in experiments 1, 2, and 3 were sieved to determine the quantity of nuts left in the soil.

The results of sieving for experiments 2 and 3 will be given as examples since there was no significant difference in the sieving results for experiments 1 and 7. The yields for the dusted and nondusted half of each block were compiled for harvested nuts, nuts left in the soil, and total yield of nuts (Table 5). In both of these experiments sulfur significantly increased the yields of nuts retained on vines,

but the nondusted plants shed more nuts than the sulfur-dusted plants. If total yields of nuts, that is the nuts on the vines plus those sieved out of the soil, should be considered as the response to sulfur, then in experiment 2 sulfur had no effect on the yields while in experiment 3 it had only a slight effect. In other words, opposite conclusions could be drawn from the two sets of data. The data this season seem to show that sulfur prevented decay of the pegs, making it possible to harvest more of the nuts with the vines rather than increasing the total production of nuts by controlling the leaf diseases. These experiments indicate how important it is in dusting and fertilizer experiments to have information in regard to total yields. Without that information it appears that it would be difficult to evaluate accurately the effect of treatment on the yield of peanuts.

TABLE 5.—*The influence of sulfur dusting on average yield in pounds per acre of peanuts retained on vines, peanuts left in soil, and total yields per sub-block in experiments 2 and 3.*

Treatment	Peanuts retained on vines, lbs.		Peanuts sieved out of soil, lbs.		Total yield, lbs.	
	Average	% increase	Average	% increase	Average	% increase
			Experiment 2			
Dust..	1,119*	14.0	142	—	1,261	—
No dust.	982	—	303	113.4	1,285	1.9
			Experiment 3			
Dust...	1,196**	51.4	226	—	1,422*	12.8
No dust.	790	—	470*	108.0	1,260	—

*Significant at the 5% level.
**Significant at the 1% level.

DISCUSSION

Sulfur treatments significantly increased the yield of peanuts in only one of seven experiments. Peanut hay yields were significantly increased by sulfur in three of the experiments. These results suggest that sulfur had little effect in contrast to what has been reported. Dusting was done at different dates all through the summer, and if the time of dusting is a factor it would seem that some of the applications would have been more effective. No explanation is offered for the lack of sulfur response in 1944.

The amount of peanuts left in the soil is of importance in any study involving yield data. More than 900 pounds of nuts per acre were left in the soil in some plots when harvested by the ordinary digging process. Several authors (7, 9, 10) state that many nuts may be left in the soil. Others (2, 7) indicate that sulfur dust delays the maturity of peanuts. One writer (10) states that when sulfur dust is properly applied diseases of the pegs are negligible and few nuts are left in the soil. Due to the above factors and to the fruiting habit of the peanut, it might be difficult to determine the correct time to harvest and as a result a certain percentage of the nuts are always left in the soil.

Crops of some plants of indeterminate growth habit are usually harvested two to three times during a season which is impossible with the peanut. The Runner peanut has an indeterminate growth habit and may flower almost incessantly over a period of approximately two months (13). The fruits are distributed from the basal to the terminal region of the branches or occur in clusters along the branches (7, 11, 15). The nuts mature in the sequence of flowering and when plants are harvested some of the mature nuts at the bases of the runners have passed maturity and are left in the soil, while the ones at the terminal ends are immature.

Some authors (4, 16) have mentioned that results obtained from experiments with peanuts are frequently inconsistent. Could it be that the inconsistent results are due in part to incomplete yield records? The results in Table 5 show how it might be possible to draw erroneous conclusions from incomplete yields. Fertilizer treatment influences the yield of peanuts (3, 14). Therefore, treatment would be expected to influence the number of fruits set and the date of maturity of the nuts. When plants receive different cultural treatments and are all harvested at the same period is it not possible that plants of some treatments are favored while others are at a disadvantage?

To evaluate properly the complete effect of treatment it would seem that total yields, nuts harvested and nuts left in the soil, and the amount of shrivels, as an index of maturity, would be necessary for interpretation of results.

CONCLUSIONS

The results presented in this paper seem to justify the following statements:

1. In general, sulfur treatments did not materially affect the total yields of peanuts in field experiments at Gainesville, Fla., in 1944.
2. In two experiments there were significant increases in the yields of the nuts on the vines, but when the amount of nuts left in the soil were added to those there was no material difference in the total yields of the dusted and nondusted treatments, suggesting that sulfur only caused a higher percentage of peanuts to remain on the vines.
3. The maturity of peanuts with different treatments should be considered in deciding on the date of harvest.
4. The amount of nuts left in the soil is an important factor in the interpretation of yield data of peanuts. Examples are given where opposite conclusions could be drawn with and without information on the quantity of nuts left in the soil. This suggests that it is practically impossible to prove what effect treatments have on the yields of peanuts without having complete information.

LITERATURE CITED

1. ANONYMOUS. Peanuts and soybeans. N. C. Agr. Exp. Sta., 66th Ann. Rpt., 41–53. 1943.
2. BATTEN, E. T., and POOS, F. W. Spraying and dusting to control the potato leafhopper on peanuts in Virginia. Va. Agr. Exp. Sta. Bul. 316. 1938.

3. BURKHART, LELAND, and COLLINS, E. R. Mineral nutrients in peanut growth. Soil Sci. Soc. Amer. Proc., 6:272–280. 1942.
4. COLLINS, E. R., and MORRIS, H. D. Soil fertility studies with peanuts. N. C. Agr. Exp. Sta. Bul. 330. 1942.
5. GORE, U. R. Culture and fertilizer studies with peanuts. Ga. Agr. Exp. Sta. Bul. 209. 1941.
6. HEBERT, T. T., and SHAW, LUTHER. Studies on the control of cercospora leaf spots of peanuts. Proc. Assoc. South. Agr. Workers, 42:51. 1941.
7. MILLER, LAWRENCE I. Peanut leafspot and leafhopper control. Va. Agr. Exp. Sta. Bul. 338. 1942.
8. MORGAN, M. F. Chemical soil diagnosis by the universal soil testing system. Conn. Agr. Exp. Sta. Bul. 450. 1941.
9. POOS, F. W., and BATTEN, E. T. Greatly increased yields of peanuts obtained in attempts to control potato leafhopper. Jour. Econ. Ent., 30:561. 1937.
10. PRINCE, ALTON E. Diseases of peanuts in North Carolina. Plant Dis. Reporter, 28:1080–1081 (No. 35). 1944.
11. REED, E. L. Anatomy, embryology and ecology of *Arachis hypogea*. Bot. Gaz., 78:289–310. 1924.
12. SHAW, LUTHER. Further studies on the control of cercospora leafspot of peanuts with various dusts and sprays. Proc. Asso. South. Agr. Workers, 41:194. 1940.
13. SHIBUYA, T. Morphological and physiological studies on the fructification of peanut. Mem. Fac. Sci. and Agr., Taihoku Imp. Univ., 17:1–120. 1935.
14. SOMMER, A. L., WEAR, J. I., and BAXTER, A. The response to magnesium of six different crops on sixteen Alabama soils. Soil Sci. Soc. Amer. Proc., 5:205–212. 1941.
15. STOKES, W. E., and HULL, F. H. Peanut breeding. Jour. Amer. Soc. Agron., 22:1004–1019. 1930.
16. WEST, H. O. Peanut production. Miss. Agr. Exp. Sta. Bul. 366. 1942.
17. WOODROOF, NAOMI C. Increased yields of spanish peanuts obtained by dusting. Ga. Agr. Exp. Sta. Cir. 136. 1942.
18. ———, and HIGGINS, B. B. Dusting Spanish peanuts with sulfur. Ga. Agr. Exp. Sta. Circ. 117. 1939.

THE EFFECT OF CALCIUM ON CERTAIN CHARACTERISTICS OF PEANUT FRUIT[1]

W. E. COLWELL AND N. C. BRADY[2]

THE effects of various elements on the yield of peanuts and the development of kernels have already been discussed (1, 2, 3).[3] The present paper deals with certain characteristics of peanut fruit as affected by calcium supply.

On soils low in calcium, applications of calcium sulfate to the foliage at blooming time have been found markedly to increase yields and kernel development of large-seeded type peanuts (1, 2). Additions of potassium or magnesium sulfate were, in general, slightly detrimental to fruit filling. Also, the use of dolomitic limestone did not result in proper kernel development.

That the nutrient requirements of peanuts must be considered on the basis of variety has been pointed out (3). For example, large-seeded type peanuts have been found to respond much more to calcium additions than the small-seeded Spanish varieties. For this reason, in this paper consideration will be given to differences due to varieties.

The data reported herein were obtained simultaneously with those on yield and quality from the field experiments referred to above. This was made possible through the use of classification and sampling technics which have been described in detail elsewhere (2). Particular attention was given to the effects of nutrients upon (a) the proportion of 2-cavity size fruit, (b) the percentage fill in the 1- and 2-cavity size fruits, and (c) average weights of kernels from several fruit categories.

In some of the experiments referred to above, three varieties of small-seeded peanuts were compared with Virginia Bunch, and data are therefore available to compare the effects of treatments on the fruit characteristics of the four varieties.

Since the treatments used varied somewhat from experiment to experiment, their description is given in Table 1. The locations are designated in all tables by the initials of cooperating growers.

RESULTS AND DISCUSSION

PROPORTION OF TWO-CAVITY SIZE FRUIT AS AFFECTED BY CALCIUM, MAGNESIUM, AND POTASSIUM

Peanuts were classified in such a manner that it was possible to calculate the percentage of the fruit in a given sample which contained either 3, 2, or 1 ovarian cavities.[4] Since the percentage of fruit in the 3-cavity size group was very small, varying from 0.0 to 5.0%, the fruit of the 1- and 2-cavity size groups constituted virtually 100%

[1]Contribution from the Department of Agronomy, North Carolina Agricultural Experiment Station, Raleigh, N. C. Published with the approval of the Director as Paper No. 210 of the Journal Series. Received for publication March 21, 1945.

[2]Associate Agronomist and Assistant in Agronomy, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 708.

[4]A peanut fruit has one or more compartments in each of which one kernel may form. An individual compartment is referred to as an ovarian cavity.

TABLE 1.—*Treatment designations and descriptions at each of seven locations.*

Treatment designation	Source	Rate in lbs. per acre	Placement
		Location MLW	
O.......	No treatment	———	———
K......	K_2SO_4	48 lbs. K_2O	Rooting or fruiting medium as indicated
Mg.. ..	$MgSO_4.H_2O$	15 lbs. MgO	
Ca	$CaSO_4.2H_2O$	400 pounds	
K-K....	K_2SO_4	96 lbs. K_2O	One half placed 3–5 inches below the seed at planting and one half on the row at early bloom
Mg-Mg .	$MgSO_4.H_2O$	30 lbs. MgO	
Ca-Ca	$CaSO_4.2H_2O$	800 lbs.	
		Locations RPF, FWR, ZRW, and RD	
CK.....	No treatment	———	———
G.......	$CaSO_4.2H_2O$	400 lbs.	On the row at early bloom
K......	KCl	45 lbs. K_2O	Top dressed at emergence
L.......	Dolomitic lime	400 lbs.	In row at planting
		Locations WAT and ENE	
CK.....	No treatment	———	———
G..	$CaSO_4.2H_2O$	400 lbs.	On the row at early bloom
K......	KCl	48 lbs. K_2O	In row at planting
L.......	Dolomitic lime	400 lbs.	In row at planting

of the total. Thus, the main effect of treatment may be shown by reporting values from either of the latter groups. In the present study, the percentages of fruits containing 2 cavities are reported.

At location MLW (Ex.Ca 0.50 M.E. per 100 grams) comparisons of the effects of various placement combinations of the sulfates of calcium, potassium and magnesium showed that the fruiting medium[5] application of calcium sulfate resulted in a higher proportion of 2-cavity size fruit than did any other treatment (Fig. 1). This beneficial effect was noted regardless of rooting medium treatment.

There was a tendency for potassium placed in the fruiting medium to reduce the percentage of 2-cavity size fruit, the decrease being significant when with it, magnesium was supplied to the rooting medium. Magnesium placed in the fruiting medium decreased the percentage of 2-cavity size fruit except when accompanied by calcium in the rooting medium. The effects of these three cations in varying the proportion of fruit sizes are in general similar to those obtained on yield and kernel development (1), but the differences observed were of much smaller magnitude.

The effects of calcium and potassium on the proportion of fruits in the two size groups were determined at several other locations. Data from five of these where soil calcium varied from 0.21 to 1.39 M.E. per 100 grams soil are shown in Fig. 2.

[5]The term "fruiting medium" refers to the surface 3 or 4 inches of soil where the peanut fruit develop. Applications of fertilizer to this zone were made in early July. The term "rooting medium" refers to a lower horizon of soil where root growth takes place and applications of fertilizers to this zone were made below the seed at the time of planting.

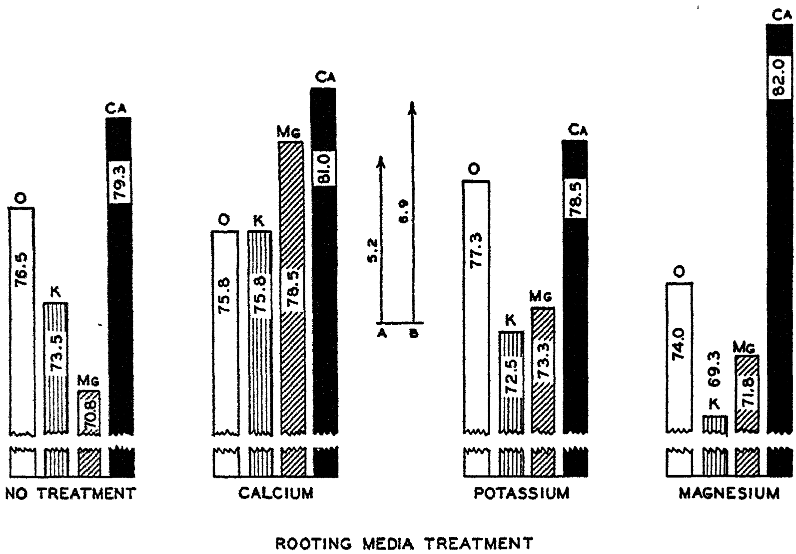

FIG. 1.—The percentage of two-cavity size fruit as affected by calcium, potassium, and magnesium. The four rooting medium treatments are indicated at the base of the graph and consist of the following: No treatment, and the sulfates of calcium, potassium, and magnesium. At each of these, the same variables with respect to quantities of these elements occur as fruiting medium treatments. The latter are indicated by symbols above their respective bars. Complete treatment descriptions are given in Table 1. A = L.S.D. (.05) and B = L.S.D. (.01). Location MLW.

It is readily noted that the use of gypsum on the three soils lowest in calcium resulted in fruits of which a significantly higher proportion were of the 2-cavity size. This treatment exerted a marked beneficial effect on yield and kernel development at these three locations (2). At locations RD and ENE where the contents of soil calcium were somewhat higher the addition of calcium was without effect in increasing the proportion of 2-cavity fruit. At these locations, however, there was a response to calcium as measured by yield and kernel development, although it was less pronounced than that which occurred on the three soils of lowest calcium contents.

The effect of the limestone treatment on two of the soils low in calcium was beneficial, although not to the same degree as was gypsum. Potash did not affect the proportion of 2-cavity fruit in any of the experiments.

At four locations N. C. Runner, Spanish 2B, and White Spanish varieties were grown along with Virginia Bunch. The effects of treatment on the proportion of 2-cavity fruit of N. C. Runner is shown in Fig. 3. As with Virginia Bunch, added calcium exerted a marked increase in the percentage fruit of 2-cavity size on the three soils lowest in calcium. Gypsum was again without significant effect at location RD where soil calcium was relatively high.

Corresponding data from Spanish 2B and White Spanish varieties showed essentially no effect of calcium on the proportion of 2-cavity

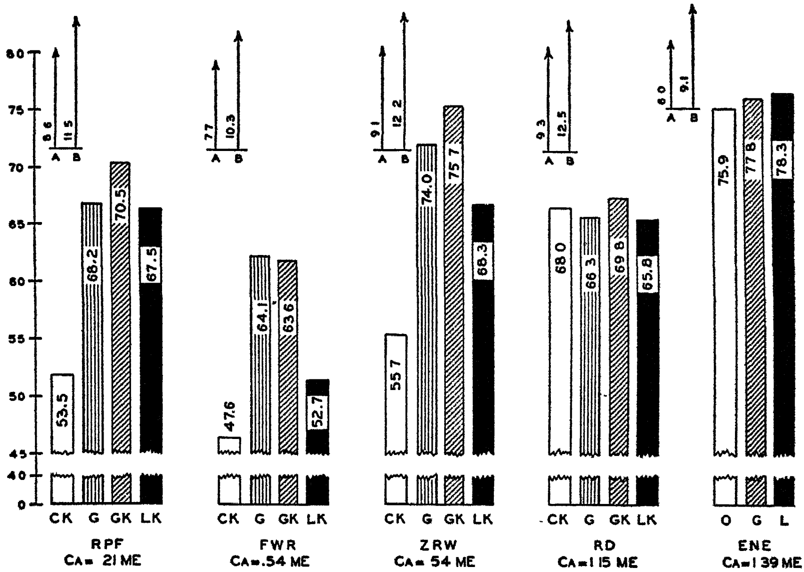

FIG. 2.—The proportion of two-cavity fruit of large type peanuts as affected by fertilizer treatment at five locations. Virginia Bunch at all locations except ENE, where Jumbo Runner was used. See Table 1 for treatment descriptions. A = L.S.D. at the .05 level; B = L.S.D. at the .01 level.

fruit (Table 2). The comparative behavior of the four varieties with respect to added calcium is in agreement with the observed effects of this element on yield and kernel development (3).

Although a complete explanation of the effects of calcium on these fruit characteristics cannot be made, supplementary morphological data recently obtained by Smith (4) provide a basis for certain postulations. An examination of a large number of ovaries of the Jumbo Runner and Spanish 2B varieties in late bud and open flower stages showed the presence of at least two and occasionally three ovules. In some 400 cases, he did not find an ovary which contained only one ovule. Thus, it may be assumed that in the 1-cavity size

TABLE 2.—*The effects of treatment on the percentage of fruit of 2-cavity size of two varieties at four locations.*

Treatment*	Spanish 2B				White Spanish			
	RPF	FWR	ZRW	RD	RPF	FWR	ZRN	RD
Ck	65.2	57.7	67.7	77.0	60.1	62.1	69.0	70.0
G	66.8	68.2	70.7	79.8	67.2	63.9	76.0	78.5
GK	72.1	71.2	72.3	79.5	68.5	71.4	71.3	79.5
LK	60.8	55.3	68.3	78.0	59.2	61.0	68.3	77.8
L.S.D. (.05)	8.6	7.7	9.1	9.3	8.6	7.7	9.1	9.3

*See Table 1 for treatment descriptions.

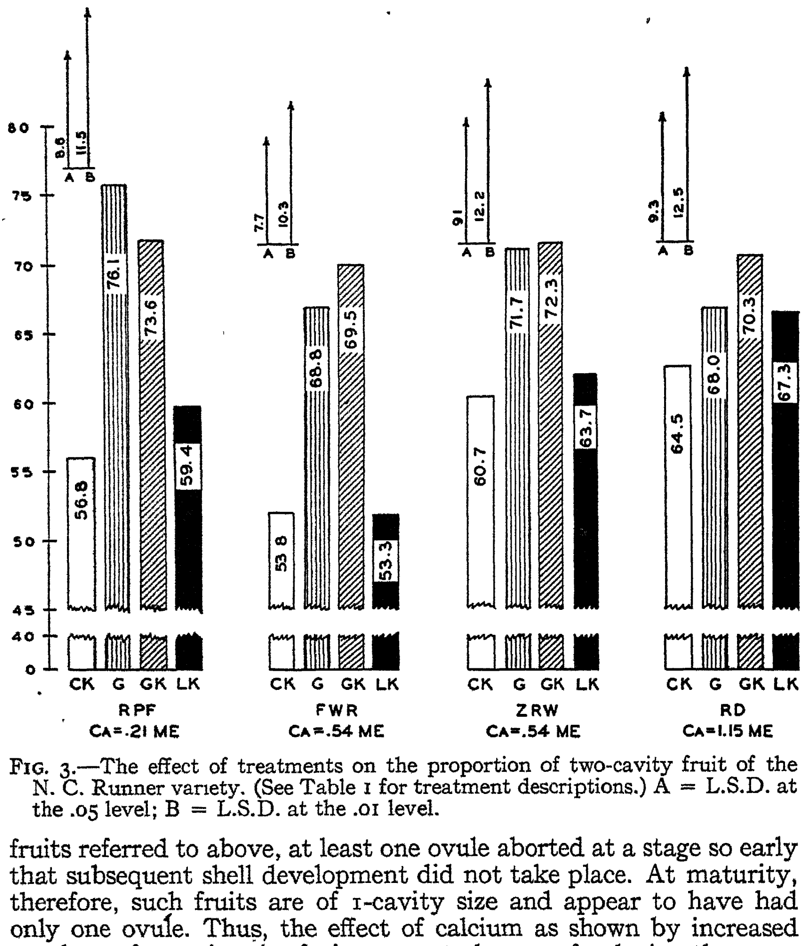

FIG. 3.—The effect of treatments on the proportion of two-cavity fruit of the N. C. Runner variety. (See Table 1 for treatment descriptions.) A = L.S.D. at the .05 level; B = L.S.D. at the .01 level.

fruits referred to above, at least one ovule aborted at a stage so early that subsequent shell development did not take place. At maturity, therefore, such fruits are of 1-cavity size and appear to have had only one ovule. Thus, the effect of calcium as shown by increased numbers of 2-cavity size fruits seems to be one of reducing the number of abortions in the initial stages of development.

This observation is particularly interesting when consideration is given to the effect of calcium in increasing the percentage of the ovarian cavities which were filled. Since in the latter case normal shell growth has occurred, and the undeveloped ovules can be seen with the naked eye, it is apparent that the effect of calcium has been one associated with the prevention of abortion at a comparatively late stage in fruit development. If this is true, the effect of calcium in the two cases noted might be assumed to be the same, i.e., the prevention of abortion; the principal difference being the stage at which it is exerted.

Of interest concerning the role of calcium in fruit development are (a) the data in Fig. 2 which show that on the two soils of highest calcium levels no increases in proportion of fruit of 2-cavity size resulted from the use of calcium even though this element *did exert a*

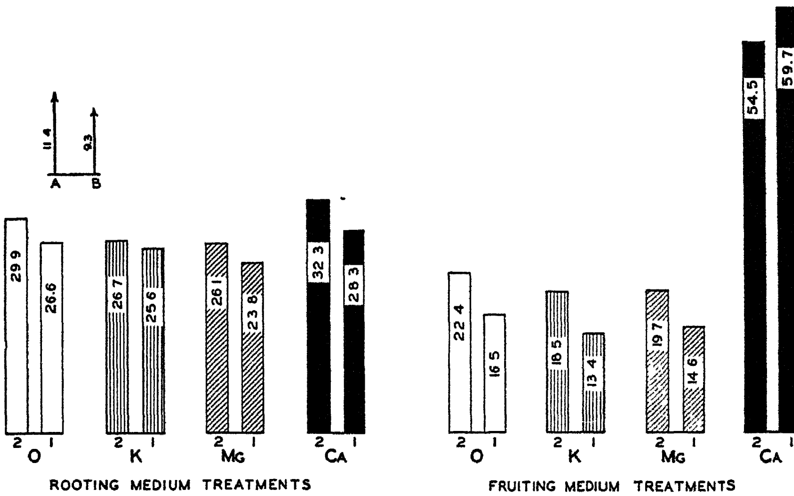

FIG. 4.—The effect of fruiting and rooting medium treatments on the filling of two- and one-cavity fruits of Virginia Bunch variety. At the left, for the four rooting medium treatments as indicated, the separate fruiting medium treatments are not presented individually; similarly at the right the rooting medium variables are not presented separately. A = L.S.D. (.05) for comparing the effects of treatment on either fruit size. B = L.S.D. (.05) for comparing the effects of fruit size at any one treatment. Location MLW.

marked beneficial effect on kernel development; (b) also, the relative increases in percentage fruit of 2-cavity size as brought about by calcium were much smaller than the corresponding increases in kernel development (2).

Thus it would appear that the level of calcium necessary to prevent abortion in the later stages is higher than that necessary to prevent abortion in the early stages. In view of these considerations, an adequate supply of calcium throughout the entire period of development would be expected to result in larger numbers of well-filled 2-cavity size fruit than would calcium supplied at later periods only.

Quite in line with this hypothesis are the results heretofore presented showing that from the soil highest in calcium (location UCP) better quality fruit were obtained without added calcium than from any other soil even with the addition of gypsum.

PERCENTAGE FILL IN THE TWO- AND ONE-CAVITY FRUITS AS AFFECTED BY TREATMENT

By classifying peanut fruit according to the procedure referred to earlier in this paper, it was possible to determine the effect of treatment not only upon the proportion of fruits of a given size as just discussed, but also the effect of treatment upon percentage fill in each of the 2- and 1-cavity size fruits.

Data on Virginia Bunch variety from location MLW presented in Fig. 4 show that, in general, there was relatively higher percentage fill in the fruit of the 2-cavity size. Additional data on large type

peanuts from six experiments presented in Table 3 show also that, in general, there was a higher percentage fill in fruits of the 2-cavity size than in fruits of the 1-cavity size. Furthermore, soil treatment did not alter this relationship even though the actual values were raised considerably by the use of calcium. It is evident that for the Virginia Bunch variety fruit of both groups responded to calcium to approximately the same degree, with a slightly poorer fill in the fruits of the 1-cavity size.

TABLE 3.—*The effects of treatment on the percentage fill of 2- and 1-cavity size fruits of large type peanuts.**

Treatment†	Percentage ovarian cavities filled		Percentage ovarian cavities filled	
	2-cavity fruit	1-cavity fruit	2-cavity fruit	1-cavity fruit
	Location ZRW		Location RD	
Ck	11.6	5.9	17.0	14.7
G	39.0	35.8	38.3	25.8
GK	36.6	35.3	44.3	32.3
LK	20.4	15.8	13.3	9.8
Average..........	26.9	23.2	28.2	20.7
L.S.D. (.05)	a = 8.7 b = 6.8 c = 3.4		a = 14.3 b = 14.7 c = 7.4	
	Location FWR		Location RPF	
Ck	13.5	8.6	14.7	16.2
G	39.8	28.1	52.3	45.0
GK	37.7	29.6	46.4	46.3
LK	14.5	6.9	25.9	11.2
Average..........	26.4	18.3	34.8	29.7
L.S.D. (.05)	a = 10.2 b = 8.7 c = 4.4		a = 7.0 b = 6.4 c = 3.5	
	Location WAT		Location ENE	
Ck	39.7	30.1	30.3	25.5
G	66.9	57.1	42.7	43.0
L	69.6	56.0	31.5	15.1
Average..........	58.7	47.7	34.8	27.9
L.S.D. (.05)	a = 15.5 b = 10.4 c = 5.2		a = 14.3 b = 10.9 c = 5.5	

*Four replications at RD, FWR, and RPF, and three at ZRW, WAT, and ENE. Virginia Bunch variety at all locations except at ENE where Jumbo Runner were grown. a = L.S.D. (.05) for comparing values within a given fruit size column; b = L.S.D. (.05) for comparing values at a given treatment level; c = L.S.D. (.05) for comparing average values.

†See Table 1 for treatment descriptions.

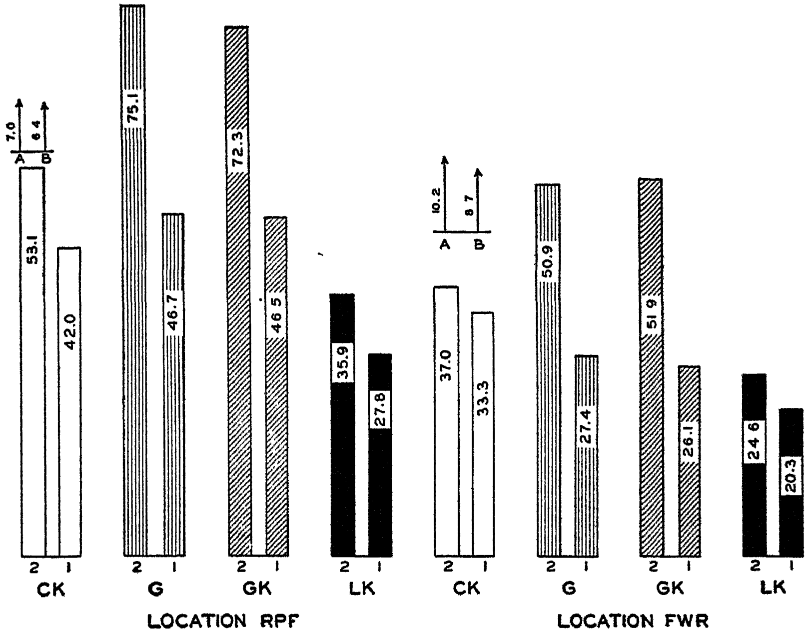

FIG. 5.—The effect of treatments on the filling of two- and one-cavity fruits of the N. C. Runner variety. A = L.S.D. (.05) for comparing the effects of treatment on the filling of either fruit size. B = L.S.D. (.05) for comparing the effect of fruit size at any one treatment.

Since at four locations four varieties were grown under comparable conditions, data are at hand to compare varietal behavior with respect to the effect of treatment on the percentage fill in fruit of the two sizes. In contrast to the slight effect of treatment noted for Virginia Bunch, data from the N. C. Runner variety presented in Table 4 and Fig. 5 show that the percentage fill of the 1-cavity size is rather constant, whereas that of the 2-cavity size is markedly influenced by treatment. Although the calcium response of N. C. Runner, as measured in terms of yields of kernels per acre, was not found to be as great as that of Virginia Bunch (3), it is apparent that kernel development in the *2-cavity* fruit was affected more by calcium supply than that of the corresponding fruit from the Virginia Bunch.

Data for the Spanish 2B variety at the four locations are given in Table 5. As with N. C. Runner, calcium exerted a greater effect upon kernel development in fruit of the 2-cavity size. As shown by the data in Table 6, both fruit sizes of the White Spanish variety responded to calcium in about the same degree. Thus, in this respect, the behavior of White Spanish and Virginia Bunch is quite similar and is in marked contrast to that of either N. C. Runner of Spanish 2B.

The most consistent effect noted in these data, aside from that of calcium response, is the relatively high percentage of cavities filled in the 2-cavity fruits. This is particularly interesting since it is the exact opposite to what one might expect on the basis of ovule

TABLE 4.—*The effects of treatment on the percentage fill of 2- and 1-cavity size fruits of the N. C. Runner variety.**

Treatment†	Percentage ovarian cavities filled		Percentage ovarian cavities filled	
	2-cavity fruit	1-cavity fruit	2-cavity fruit	1-cavity fruit
	Location ZRW		Location RD	
Ck	37.8	29.2	46.7	36.8
G	63.7	39.4	49.7	42.6
GK	60.4	41.0	47.1	36.3
LK	35.5	22.3	44.1	30.2
Average.	49.4	33.0	46.7	36.5
L.S.D. (.05)	a = 8.7 b = 6.8 c = 3.4		a = 14.3 b = 14.7 c = 7.4	

*Three replications at ZRW; four at other location. a = L.S.D. (.05) for comparing values within a given fruit size column; b = L.S.D. (.05) for comparing values at any given treatment level; c = L.S.C. (.05) for comparing average values.
†See Table 1 for treatment descriptions.

competition. In other words, it is conceivable that a given ovule, regardless of the fruit in which it grows, requires certain constituents for its development. Other things being equal, on the basis of competition between ovules one might expect a smaller percentage of the ovules to develop in fruits which contained 2 cavities.

According to Smith's (4) results already referred to, however, it is likely that comparisons between fruits of different cavity sizes, are invalid due to physiological abnormality of the 1-cavity fruits which resulted from early stage abortion. If this is true, any explanation based on competition alone would be inadequate.

Although it has been shown (4) that 1-cavity fruits have likely resulted from an ovule abortion at a very early stage of development, the stage at which this occurs is not known. Without this information an adequate explanation of the better filling of 2-cavity fruit is difficult to make. If the early abortion occurred before the gynophore struck the ground, the internal environmental conditions responsible may have affected the remaining ovule in such a manner that subsequent normal development was less certain. If, on the other hand, the gynophore had penetrated the ground before the first abortion occurred, the external environment may have been responsible for poor filling of 1-cavity fruit. It is conceivable that soil conditions, including soil calcium, were such in the immediate vicinity of the penetrating gynophore that the development of one ovule and the surrounding shell was prevented. If the remaining ovule developed, it had to do so in the same area of the soil wherein conditions for such development were probably unfavorable. These unfavorable effects evidently outweighed any advantage from the standpoint of competition that the one ovule had and fewer developed ovules in the 1-cavity fruits resulted.

TABLE 5.—*The effects of treatment on the percentage fill of 2- and 1-cavity size fruits of the Spanish 2B variety.**

Treatment†	Percentage ovarian cavities filled		Percentage ovarian cavities filled	
	2-cavity fruit	1-cavity fruit	2-cavity fruit	1-cavity fruit
	Location FWR		Location RPF	
Ck	37.6	34.1	52.4	63.2
G	61.1	51.4	74.7	65.6
GK	53.9	49.5	71.1	60.4
LK	30.7	29.8	37.7	44.5
Average.	45.8	41.2	39.0	58.4
L.S.D. (.05)	a = 10.2 b = 8.7 c = 4.4		a = 7.0 b = 6.4 c = 3.5	
	Location ZRW		Location RD	
Ck	44.9	49.5	50.4	38.5
G	63.7	56.3	60.9	43.4
GK	64.4	51.2	56.8	38.9
LK	47.1	41.8	46.9	35.7
Average.	55.0	49.7	54.3	39.1
L.S.D. (.05)	a = 8.7 b = 6.8 c = 3.4		a = 14.3 b = 14.7 c = 7.4	

*Three replications at ZRW; four at other locations. a = L.S.D. (.05) for comparing values within a given fruit size column; b = L.S.D. (.05) for comparing values at any given treatment level; c = L.S.D. (.05) for comparing average values.
†See Table 1 for treatment descriptions.

WEIGHTS OF KERNELS FROM TWO- AND ONE-CAVITY FRUIT

After the fruits were classified and counted, the kernels from certain categories were weighed so that it was possible to determine average weights of kernels from the 2-cavity size fruits which contained (a) two well-developed kernels and (b) one well-developed kernel; as well as average kernel weights from the 1-cavity size fruit. The effect of treatment on the weight of kernels from the three fruit categories from one location is shown by the data in Table 7. Calcium placed in the fruiting zône, the only treatment markedly to affect fruit filling and yield, resulted in a significant increase in kernel weights. Other treatments had no significant effects.

Data from eight locations on the kernel weights in each of the three categories referred to above are presented in Table 8. Differences due to treatment are not presented and only the average values of all treatments are used. In all of the experiments except one (ENE), the average weights of kernels from 2-cavity fruits wherein both ovules developed were smaller than corresponding fruits in which only one ovule developed. Although the differences are not extremely large, most of them are significant.

TABLE 6.—*The effects of treatment on the percentage fill of 2- and 1-cavity size fruits of the White Spanish variety.**

Treatment†	Percentage ovarian cavities filled		Percentage ovarian cavities filled	
	2-cavity fruit	1-cavity fruit	2-cavity fruit	1-cavity fruit
	Location FWR		Location RPF	
Ck	63.9	53.8	75.4	74.3
G	65.8	65.7	81.6	79.1
GK	67.6	61.9	80.8	79.4
LK	55.7	50.2	67.3	59.8
Average	63.3	57.9	76.3	73.2
L.S.D. (.05)	a = 10.2 b = 8.7 c = 4.35		a = 7.0 b = 6.4 c = 3.5	
	Location ZRW		Location RD	
Ck	64.8	61.1	75.0	65.2
G	72.2	69.5	77.7	69.1
GK	67.9	65.1	67.2	63.8
LK	65.2	62.8	71.9	65.2
Average..........	67.5	64.4	73.0	65.8
L.S.D. (.05)	a = 8.7 b = 6.8 c = 3.4		a = 14.3 b = 14.7 c = 7.4	

*Three replications at ZRW; four at other locations. a = L.S.D. (.05) for comparing values within a given fruit size column; b = L.S.D. (.05) for comparing values at any given treatment level; c = L.S.D. (.05) for comparing average values.
†See Table 1 for treatment descriptions.

TABLE 7.—*The effect of rooting and fruiting media treatments on the average kernel weights in grams from 2- and 1-kernel size fruit at one location (MLW).**

Treatment†	Weight of kernels from treatment placed in	
	Rooting zone	Fruiting zone
O-O	0.711	0.667
Ca-Ca	0.709	0.743
K-K	0.680	0.683
Mg-Mg	0.675	0.682
L.S.D. (.05) = .077		

*Four replications.
†See Table 1 for treatment descriptions.

Although strict comparisons between the filling of 2- and 1-cavity fruits on the basis of ovule competition may not be valid, this basis can be used in accounting for the differences in development of kernels in a given cavity size fruit. Thus, in two-cavity fruits wherein

TABLE 8.—*The effect of fruit size on weights in grams of kernels at eight different locations.*

Location	Kernel weights in fruit of			L.S.D. (.05)
	2-cavity size		1-cavity size: 1 developed	
	2 developed	1 developed		
(MLW)	0.646	0.708	0.727	0.061
(RPF)	0.548	0.593	0.587	0.049
(FWR)	0.515	0.542	0.530	0.026
(ZRW)	0.524	0.573	0.553	0.067
(RD)	0.472	0.511	0.497	0.060
(WAT)	0.650	0.725	0.702	0.045
(ENE)	0.819	0.784	0.840	0.168
(MPW)	0.585	0.628	0.608	0.044

*Four varieties averaged at locations RPF, FWR, ZRW, and RD; at ENE Jumbo Runner variety; at other locations Virginia Bunch only.

one ovule has aborted, it is probable that the supply of nutrients for development of the remaining ovule is greater than would be the case had both ovules developed normally. There would be no competition for nutrients within a given 2-cavity fruit when only one ovule developed and as a result larger kernels would be expected.

SUMMARY AND CONCLUSIONS

Hand-picked peanuts from field experiments in which calcium, potassium, and magnesium variables had been established were classified on the basis of fruit cavity size and kernel development. Such a classification made possible the determination of (a) the proportion of 2-cavity size fruit, (b) the percentage fill in the 2- and 1-cavity fruits, and (c) average weights of kernels from 2- and 1-cavity fruits.

On soils low in calcium, the use of gypsum increased the proportion of 2-cavity size fruit of the Virginia Bunch and N. C. Runner varieties but not of the Spanish 2B and White Spanish varieties. It was suggested that calcium sulfate exerted this favorable effect by preventing ovule abortion at a very early stage of fruit development before shell enlargement had begun. On soils of higher calcium level, where increases in yield and kernel development of the two former varieties had resulted from calcium additions, gypsum did not increase the proportion of 2-cavity fruits. Thus, it appears that the level of calcium necessary to prevent abortion in the later stages is relatively high in comparison to that to prevent abortion in the early stages.

For all varieties tried there was a higher proportion of the 2-cavity size fruits filled than of the 1-cavity size. For Virginia Bunch and White Spanish this ratio was unaffected by calcium supply, i.e., both classes of fruit responded to calcium in about the same degree. However, for N. C. Runner and White Spanish, added calcium exerted a relatively greater effect on the fill of the fruit of 2-cavity size.

The use of gypsum increased the average weight of peanut kernels. With all treatments combined, the average weights of kernels from 2-cavity fruits wherein both ovules developed were smaller than corresponding weights of kernels from fruits in which only one ovule developed. This difference was explained on the basis of ovule competition. The weights of kernels from 1-cavity fruits were, in general, intermediate between the two values referred to above.

LITERATURE CITED

1. BRADY, N. C., and COLWELL, W. E. Yield and quality of large-seeded type peanuts as affected by potassium and certain combinations of potassium, magnesium, and calcium. Jour. Amer. Soc. Agron., 37:429–442. 1945.
2. COLWELL, W. E., and BRADY, N. C. The effect of calcium on yield and quality of large-seeded type peanuts. Jour. Amer. Soc. Agron., 37:413–428. 1945.
3. MIDDLETON, G. K., COLWELL, W. E., BRADY, N. C., and SCHULTZ, E. F., JR. The behavior of four varieties of peanuts as affected by calcium and potassium variables. Jour. Amer. Soc. Agron., 37:443–457. 1945.
4. SMITH, B. W. The reproductive morphology of the peanut, *Arachis Hypogaea*. (In press).

THE RELEASE OF EXCHANGEABLE AND NONEXCHANGEABLE POTASSIUM FROM DIFFERENT SOILS UPON CROPPING[1]

ROBERT F. CHANDLER, JR., MICHAEL PEECH, AND C. W. CHANG[2]

THE exchangeable potassium content of most dairy farm soils in New York State ranges from 25 to 250 pounds per acre in the surface layer. Thus the amount of potassium in exchangeable form found at any one time is usually less than that removed in one season by two cuttings of alfalfa. In order that such soils may be cropped successfully for years without potassium fertilization, part of the potassium required by the crop must be supplied by the nonexchangeable potassium either directly or after being converted to the exchangeable form. This idea, of course, is not new. Fraps (5),[3] Abel and Magistad (1), Hoagland and Martin (6), Bray and DeTurk (3), Bear, Prince, and Malcolm (2), as well as others, have shown that the amount of exchangeable potassium present at any one time is only sufficient to meet the crop requirement for one or two years.

Experience in New York State has shown that alfalfa soils under similar management show marked differences in crop response to application of potassium. Some of these soils have been producing excellent yields of alfalfa for many years without the addition of potassium to the alfalfa crop, outside, of course, the application of manure or complete fertilizer to the corn crop in the rotation, whereas other soils fail to maintain satisfactory stands of alfalfa unless liberal amounts of potassium are applied. It follows, therefore, that the soils which do not require supplementary application of potassium for good growth of alfalfa must release every year a considerable amount of potassium from nonreplaceable forms. The primary object of this study was to determine the significance of the exchangeable and the nonexchangeable potassium in relation to the potassium-supplying power of these soils as measured by the yield and chemical composition of the crop.

MATERIALS AND METHODS

Ladino clover, a mammoth form of white clover, *Trifolium repens* L., was grown in the greenhouse in No. 1 enameled tin cans, containing 1 pound of soil. The lime, phosphorus, and nitrogen needs of the plants were supplied by adding C.P. calcium carbonate to all acid soils to bring the pH value between 6.5 and 7.0, by applying 20% superphosphate at the rate of 1,000 pounds per acre, and by adding 50 pounds per acre of nitrogen as ammonium sulfate and subsequently inoculating the plants. The method of watering the plants was the same as that described by Colwell (4).

After the appearance of the first leaf, the seedlings were thinned to three plants per can. Sixteen replications for each soil were started to permit the removal of

[1]Contribution from the Department of Agronomy, Cornell University Agricultural Experiment Station, Ithaca, N. Y. This paper was originally presented before the Fertilizer Division of the American Chemical Society at the annual meeting in New York City, September, 1944, and was subsequently released for publication in this JOURNAL. Received for publication March 27, 1945.

[2]Associate Professors and formerly Research Associate, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 720.

the soil from two cans at each harvesting date for the determination of the dry weight and composition of the roots. The soil from these two cans was saved for the determination of exchangeable potassium. The plants were harvested every two or three months at the early bloom stage and the tops were saved for the determination of the dry weight and the potassium content. It was thus possible to calculate (a) the total amount of potassium removed by the tops and roots, (b) the decrease in exchangeable potassium, and (c) the amount of nonexchangeable potassium absorbed by the crop.

Two separate experiments were conducted. In experiment 1, four soils were continuously cropped until plants could no longer be grown because of potassium deficiency. In experiment 2 the results of four separate harvests are reported. The plants on the Bath and Honeoye gravelly silt loam soil were showing marked deficiency of potassium at the end of the experiment.

The potassium content of the roots and tops was determined by the cobaltinitrite method (8). The exchangeable potassium content of the soil was determined by the ammonium acetate procedure (7) employing the volumetric cobaltinitrite method.

EXPERIMENTAL RESULTS

The data in Table 1 show the exchangeable potassium content of the 11 different soil types at the start and during the course of each experiment. To show the trends readily, the data for three contrasting soils are presented in Fig. 1.

The data from experiment I, in which all soils were cropped until the plants could no longer obtain sufficient potassium to maintain growth, show that all soils except the Honeoye silt loam started out with a relatively low amount of exchangeable potassium which decreased slightly during the first two cropping periods, and which, subsequently, remained rather constant. These three soils had been cropped intensively for many years before the samples were taken

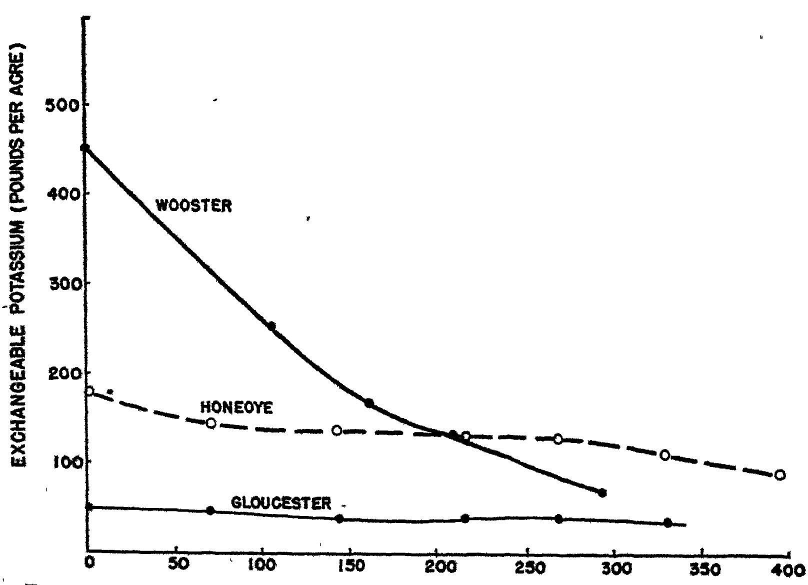

FIG. 1.—The exchangeable potassium content of three soils during the cropping period.

TABLE 1.—*The change in the exchangeable potassium content of the 11 soil types studied during the course of the experiment.*

Soil type	Exchangeable potassium expressed as pounds per acre*						
	At start	After 1st crop	After 2nd crop	After 3rd crop	After 4th crop	After 5th crop	After 6th crop
	Experiment I						
Honeoye silt loam	183	149	140	136	133	114	91
Dunkirk silty clay loam	59	57	57	50	50	50	—
Mardin silt loam	75	57	50	43	44	42	—
Gloucester loam	50	48	40	39	40	38	—
	Experiment II						
Wooster silt loam	450	253	174	137	75	—	—
Palmyra gravelly sandy loam	417	266	159	112	97	—	—
Chenango gravelly silt loam	225	200	143	127	120	—	—
Palmyra gravelly silt loam	220	143	130	103	83	—	—
Bath silt loam	108	65	58	61	51	—	—
Ontario loam	69	52	65	61	56	—	—
Honeoye gravelly silt loam (Marcellus area)	67	—	—	67	67	—	—

*Based on 2,000,000 pounds of soil.

and little if any potash fertilizers had been added. The Honeoye silt loam also had been cropped intensively without potash fertilization prior to the time the sample was taken. But it will be noted that the exchangeable potassium content of this soil at the start was 183 pounds per acre and remained at a relatively high level, 91 pounds, even after continuous cropping for 391 days.

This is also true for some of the soils studied in experiment II. The Palmyra and Chenango series, showing high exchangeable potassium content at the start, maintained relatively high amounts even after four crops had been grown. Further cropping would be necessary to determine the level at which the exchangeable potassium will become more or less constant under continuous cropping. The Bath, and particularly the Ontario and Honeoye soils, having low exchangeable potassium at the start of experiment II, apparently reached this stage. It is interesting to note that when a large amount of exchangeable potassium was present initially in the soil, the exchangeable potassium content decreased rather rapidly upon cropping. The Wooster soil sample was taken from a road cut and had not been cropped for many years. The high exchangeable potassium level shown by this soil cannot be maintained upon intensive cropping. Nearly one-half of the initial exchangeable potassium of this soil was removed by the first crop and more than 80% by the four crops combined. The significance of these data will be considered later.

The potassium content and the dry weights of the Ladino clover plants per can are presented in Table 2, and graphically for three soils in Fig. 2.

These data show that the potassium content of the tops was related to the amount of exchangeable potassium in the soil. The amount of potassium in the plants of the consecutive crops decreased during

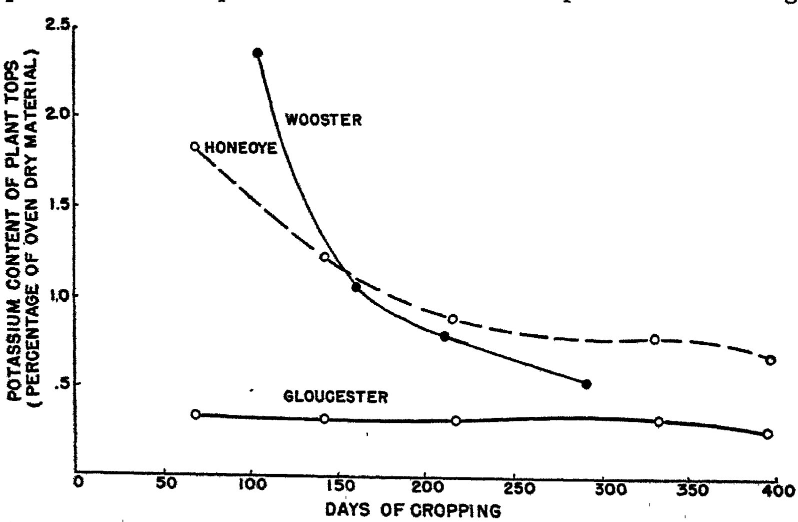

FIG. 2.—The potassium content of Ladino clover plants grown on three different soils.

TABLE 2.—*The potassium content and yields of tops of Ladino clover plants during the course of the experiment.*

Soil type	1st crop		2nd crop		3rd crop		4th crop		5th crop		6th crop	
	Dry weight, grams	K content, %	Dry weight, grams	K content, %	Dry weight, grams	K content, %	Dry weight, grams	K content, %	Dry weight, grams	K content, %	Dry weight, grams	K content, %
Experiment I												
Honeoye silt loam	0.87	1.79	1.83	1.23	2.46	0.88	2.18	1.00	1.27	0.80	0.94	0.69
Dunkirk silty clay loam	0.30	1.00	1.04	0.52	1.29	0.56	0.80	0.44	0.14	0.37	—	—
Mardin silt loam	0.69	0.62	0.94	0.45	0.81	0.48	0.42	0.45	0.12	0.41	—	—
Gloucester loam	0.54	0.32	0.51	0.33	0.47	0.31	0.30	0.34	0.06	0.24	—	—
Experiment II												
Wooster silt loam	1.36	2.35	2.90	1.07	1.03	0.82	1.73	0.57	—	—	—	—
Palmyra gravelly sandy loam	1.20	2.15	2.37	1.29	0.90	0.85	1.30	0.83	—	—	—	—
Chenango gravelly silt loam	1.32	1.39	2.22	0.78	1.07	0.61	1.68	0.48	—	—	—	—
Palmyra gravelly silt loam	1.06	1.06	2.21	0.90	0.98	0.65	1.51	0.62	—	—	—	—
Bath silt loam	0.30	1.27	1.23	0.73	0.65	0.51	0.39	0.47	—	—	—	—
Ontario loam	0.50	0.46	1.55	0.78	0.77	0.68	1.55	0.47	—	—	—	—
Honeoye gravelly silt loam (Marcellus)	0.19	0.49	0.53	0.50	0.50	0.53	0.83	0.38	—	—	—	—

the course of the experiment in all cases except where the initial potassium content of the plants was so low that further reduction could not take place without the death of the plants. If the plants contained less than 0.8% potassium, deficiency symptoms appeared on the leaves.

Those soils that contained the larger amounts of exchangeable potassium generally produced the higher yields. The yields of dry matter varied at the different sampling dates because of fluctuations in the environmental conditions in the greenhouse. To conserve space, data on the dry weights and composition of the roots of harvested crops are not reported here; however, the yields and potassium content of the roots followed those of the tops, except that the yields and the potassium content of the roots were lower. The total amounts of potassium absorbed by the plants from the exchangeable and the nonexchangeable forms during the course of the experiment are reported in Table 3.

TABLE 3.—*Changes in exchangeable-potassium content of the soil induced by cropping and the amount of nonexchangeable potassium released during the cropping period.**

Soil type	Number of days of cropping	Exchangeable potassium in soil before cropping	Exchangeable potassium in soil after cropping	Amount of potassium removed by crop	Amount of potassium released from nonexchangeable forms
		Experiment I			
Honeoye silt loam	391	183	91	450	358
Dunkirk silty clay loam	330	59	50	88	79
Mardin stony silt loam	330	75	42	72	39
Gloucester sandy loam	330	50	38	28	16
		Experiment II			
Wooster silt loam	271	450	75	439	64
Palmyra gravelly sandy loam	271	417	97	436	96
Chenango gravelly silt loam	271	225	120	308	203
Palmyra gravelly silt loam	271	220	83	283	146
Bath stony silt loam	271	108	51	102	45
Ontario loam	271	69	56	150	137
Honeoye gravelly silt loam	271	67	67	41	41

*All results expressed in pounds per acre, 2,000,000 pounds of soil.

It will be noted that the amount of potassium absorbed by the clover plants was always greater than the decrease in exchangeable potassium content of the soil. This means, of course, that nonexchangeable potassium was available to the plants either directly or after being converted to the exchangeable form. In many instances the nonexchangeable potassium represented a large propor-

tion of the potassium removed by the combined crops. The amount of nonexchangeable potassium released ranged from 16 pounds to 358 pounds per acre over the entire period of time.

So far, reference has been made only to the total amount of nonexchangeable potassium released by the soil during the course of the experiment as determined by subtracting the decrease in exchangeable potassium content of the soil from the total amount of potassium removed by the tops and the roots. The cumulative amounts of nonexchangeable potassium removed by the Ladino clover tops and roots of the consecutive crops are listed in Table 4. The question may be asked as to why the release of nonexchangeable potassium ceased in several soils in which the exchangeable potassium remained constant, yet a crop was produced. (Compare Tables 1 and 4.) The answer to this question became apparent upon studying the dry weights and the potassium content of the roots in the consecutive crops. The dry weights of the roots and their potassium content decreased upon continuous cropping, particularly in the last three crops. This disintegration of the root system resulted in the liberation of a certain amount of potassium to the tops. When the cumulative amount of potassium removed by the tops and roots remained constant, within limits of error, the top growth was produced only at the expense of the declining root system, as illustrated in Fig. 3 showing the cumulative amounts of nonexchangeable potassium removed by tops and roots of the consecutive crops grown on Mardin silt loam. This same effect was noted in the Dunkirk, Gloucester, Bath, and Honeoye gravelly silt loam soils, and probably would have been apparent in all soils if they had been cropped longer.

TABLE 4.—*Cumulative amounts of nonexchangeable potassium removed by tops and roots of consecutive crops.**

Soil type	Crop 1	Crop 2	Crop 3	Crop 4	Crop 5	Crop 6
		Experiment I				
Honeoye silt loam	67	187	280	346	366	358
Dunkirk silty clay loam	15	22	81	79	79	—
Mardin silt loam	9	33	40	42	39	—
Gloucester loam	9	11	19	21	16	—
		Experiment II				
Wooster silt loam	6	73	55	64	—	—
Palmyra gravelly sandy loam	47	50	43	96	—	—
Chenango gravelly silt loam	92	123	153	203	—	—
Palmyra gravelly silt loam	11	97	90	146	—	—
Bath silt loam	−17	25	59	45	—	—
Ontario loam	−3	69	130	137	—	—
Honeoye gravelly silt loam (Marcellus area)	—†	—†	61	41	—	—

*Results expressed in pounds per acre.
†Not determined.

RELATIONSHIPS BETWEEN GREENHOUSE AND FIELD EXPERIMENTS

The 11 soils selected for this study represent soil types that are commonly encountered on dairy farms in New York. Field studies on the potassium needs of alfalfa have yielded considerable information regarding the potassium requirements of these soils. In light of this knowledge it is interesting to compare the capacity of a soil for supplying nonexchangeable potassium with its need for potash fertilization under field conditions.

The first soil listed in each table, the Honeoye silt loam, was sampled from an experimental field near Churchville, N. Y. The plot from which this sample was taken has been producing large crops of alfalfa and other forage crops since 1910 and has not received any additions of potassium. The adjacent plots have shown no crop response to applications of potassium. The fact that 358 pounds of potassium were liberated during a period of a little more than one year, when the original exchangeable potassium content was only 183 pounds per acre, is consistent with the crop response data as obtained under field conditions.

The Dunkirk silty clay loam soil was taken from the untreated plot of a fertilizer experiment at Caldwell Field near Ithaca, N. Y. This

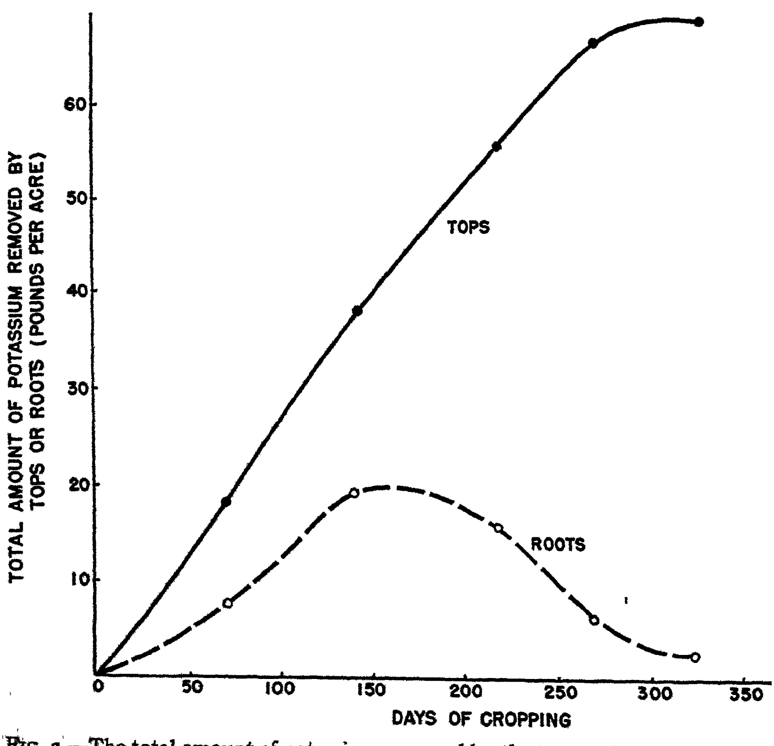

FIG. 3.—The total amount of potassium removed by the tops and roots of Ladino clover plants from Mardin silt loam soil.

soil has been cropped intensively for 30 years without potassium fertilization. The exchangeable potassium content of this soil was only 59 pounds per acre at the start of the experiment. Approximately 90% of the potassium absorbed by the combined crops was obtained from nonexchangeable sources. Both alfalfa and corn respond well to applications of potassium to this soil. Yet the average yield of corn on this soil for a 30-year period, obtained in an alfalfa-corn rotation without the addition of fertilizer except lime, is 35 bushels per acre. The exchangeable potassium content of this soil had decreased from 113 to 48 pounds per acre during the 30-year period. It is true that high crop yields cannot be obtained on this soil without the addition of potassium-carrying fertilizers, but the crop yields that have been maintained thus far emphasize the significance of the nonexchangeable potassium in the potassium-supplying power of this soil.

The Mardin silt loam and Gloucester loam are soils that invariably require potassium fertilization to produce satisfactory yields of alfalfa.

The Wooster silt loam and Palmyra gravelly sandy loam were secured from old road banks. Obviously, these soils have not been cropped for many years. This would account for the high exchangeable potassium content of these two soils. It is interesting to note how quickly the exchangeable potassium content was reduced upon cropping. It is unlikely that these two soils will continue to supply nonexchangeable potassium to the plants in sufficient amount to meet the normal crop requirement. After four crops the Wooster silt loam contained only 75 pounds per acre of exchangeable potassium; furthermore, many fields in this same area are known to respond well to applications of potassium.

The Chenango gravelly silt loam sample was obtained from a field that had been under cultivation for some time. Small amounts of potassium-containing fertilizer have been applied to this soil in the past. The fact that 203 pounds per acre of nonexchangeable potassium was utilized by the four crops, as shown in Table 3, would indicate that this soil may be cropped successfully without the use of potassium fertilizers. Experience of the farmers in the area from which this sample was taken would support this statement.

Alfalfa growing on the Palmyra gravelly silt loam seldom shows any marked response to the application of potassium. It will be noted from Table 3 that 146 pounds per acre of nonexchangeable potassium became available to the four combined crops of Ladino clover.

On the other hand, alfalfa on the Bath stony silt loam usually responds to potassium fertilization. In agreement with this observation, the yields, the potassium content of the plants, as well as the amount of nonexchangeable potassium released by this soil to the crop are low.

The sample of Ontario loam had been cropped intensively without recent additions of potassium. Despite its low initial content of exchangeable potassium, this soil released 137 pounds of nonexchangeable potassium to the four crops of Ladino clover. It seems

significant that this is one of the most productive soils in the state and many fertilizer tests have indicated no response to potassium on this soil type except in one instance.

As already noted, little if any response to potassium is shown by alfalfa on soils of the Honeoye series. However, Honeoye gravelly silt loam, used in this study, comes from an area of approximately 5 square miles near Marcellus, N. Y., in which pronounced symptoms of potassium deficiency on alfalfa were observed in many fields. Interestingly enough, no symptoms of potassium deficiency were found in alfalfa fields on Honeoye silt loam immediately surrounding this small area of Honeoye gravelly silt loam. It will be evident from the data listed in Table 1, that the exchangeable potassium content of this sample of Honeoye gravelly silt loam was low at the start of the experiment and remained constant during the cropping period. The potassium content of Ladino clover on this soil was also low and symptoms of potassium deficiency were prevalent on the leaves. All of the potassium removed by the Ladino clover plants from this soil originated from the nonexchangeable forms.

DISCUSSION

The data presented in this paper on the relative significance of the exchangeable and the nonexchangeable potassium in determining the potassium-supplying power of soils substantiates the results reported by other investigators. Fraps (5) showed that the amount of potassium absorbed by crops grown in the greenhouse for 60 days was always greater than the decrease in the exchangeable potassium content of the soil. He reported releases of nonexchangeable potassium ranging from 44 to 688 pounds per acre in the 60-day period.

Hoagland and Martin (6) in similar studies, which were conducted for 3 to 5 years, found that those soils that normally did not require potassium fertilization were capable of supplying nonexchangeable potassium at a higher rate than the potassium-deficient soils that responded well to applications of potassium fertilizers. They also showed that the addition of potassium to a soil did not affect the final level at which the exchangeable potassium became approximately constant upon continuous cropping.

Abel and Magistad (1), working with Hawaiian soils, found that upon continuous cropping for 20 months, large amounts of nonexchangeable potassium, ranging from 132 to 238 pounds per acre, were removed by the crops.

Bear, *et al.* (2) have very recently conducted studies on the potassium-supplying power of 20 New Jersey soils. They grew seven crops of alfalfa with and without potassium fertilization and calculated the amount of nonexchangeable potassium released during the entire period of cropping. Without the addition of potassium, the soils varied considerably in their capacity to supply nonexchangeable potassium. One soil released as much as 195 pounds of nonexchangeable potassium, whereas another soil actually fixed 130 pounds of exchangeable potassium per acre during the entire cropping period.

From the data presented here and those reported in the literature

it may be concluded that the amount of exchangeable potassium found in the soil at any one time, without some knowledge of the past fertilizer treatment and the cropping history, is not always a reliable measure of the capacity of the soil to supply potassium to the crop for any extended period of time. Equally important is the rate at which the nonexchangeable potassium is converted into the exchangeable form. The possibility that the nonexchangeable potassium can be utilized directly by the plants without entering the exchange complex should not be precluded. However, inasmuch as the majority of the soils can be depleted of their available supply of potassium upon continuous cropping, as was done in the present experiments, would indicate that exchangeable potassium constitutes the immediate source from which the rapidly growing crop obtains the greater part of its potassium. Indeed, high yields can only be produced when the exchangeable potassium of the soil is maintained above a certain critical level. This critical level of exchangeable potassium is characteristic for a given soil, a given crop, and a given set of environmental conditions.

In attempting to predict the need for potassium fertilization from the exchangeable potassium content of the soil it is necessary to know (a) the critical level at which maximum yields cannot be maintained without the addition of potassium, and (b) the rate at which the exchangeable potassium is replenished by that from the nonexchangeable forms. Obviously, the response to potassium fertilization can be predicted with greater accuracy from the amount of exchangeable potassium when the exchangeable potassium content of the soil is either well below or well above the critical level. When the exchangeable potassium content is near the critical level, the potassium requirement of the soil cannot be evaluated properly without some knowledge of the rate at which the nonexchangeable potassium is converted into the exchangeable form. For example, the amount of exchangeable potassium in Mardin silt loam and Ontario silt loam at the start of the experiment, as shown in Table 3, was approximately the same in both soils; but upon continuous cropping the Mardin soil released only 39 pounds of nonexchangeable potassium to the six crops of Ladino clover, whereas the Ontario soil released 137 pounds of nonexchangeable potassium as recovered by only four crops. Further work is necessary to determine to what extent the level of exchangeable potassium as found in the soil at any one time is indicative of the rate at which the nonexchangeable potassium is converted to the exchangeable form.

Little is known about the rate at which the equilibrium between the exchangeable and the nonexchangeable potassium is established. The data herein reported would indicate that this varies considerably among different soils. In some of the studies of the variation in exchangeable potassium content of New York soils, as determined at different times of the year, the authors found that the exchangeable potassium content of many soils decreases appreciably during the cropping season. The change in the exchangeable potassium content of 28 soils on which alfalfa was growing vigorously ranged from +18 to −82 pounds, with an average decrease of 18 pounds of potassium

per acre. It would appear that the determination of exchangeable potassium in the early spring and in the fall should afford some measure of the rate at which the exchangeable potassium is replenished during the winter as well as during the cropping season, and should thus enhance greatly the value of the exchangeable potassium as an index to the potassium requirement of different soils.

SUMMARY

Ladino clover was grown in the greenhouse in 11 different soils for periods ranging from 271 to 391 days. From four to six crops were harvested from each of the different soils studied and the amount of potassium removed by the tops and roots of each crop was determined. The exchangeable potassium content of the soil was determined at the start and at the time of each crop harvest. The amount of nonexchangeable potassium released was calculated by subtracting the decrease in the exchangeable potassium content of the soil from the total amount of potassium removed by the crop.

Upon continuous cropping the exchangeable potassium content of the different soils decreased very rapidly at first, then more gradually until a certain level was reached, when the potassium-supplying power of the soil was determined largely by the rate at which the nonexchangeable potassium was converted into the exchangeable form.

The dry weights and the potassium content of the plants of the successive crops were closely associated with the amount of exchangeable potassium in the soil.

The potassium content of the plants decreased upon continuous cropping. Symptoms of potassium deficiency appeared on the clover leaves when the potassium content of the plants fell below 0.8% on the oven-dry basis.

Of the 11 different soils studied, Honeoye silt loam, Chenango gravelly silt loam, and Ontario loam released large amounts of nonexchangeable potassium; whereas Mardin silt loam, Gloucester loam, and Honeoye gravelly silt loam released only small amounts of nonexchangeable potassium upon continuous cropping.

These findings are related to crop responses to potassium under field conditions. The relative significance of the exchangeable and the nonexchangeable forms of potassium in determining the potassium-supplying power of soils is discussed in light of the results obtained in this study.

LITERATURE CITED

1. ABEL, F. A. E., and MAGISTAD, O. C. Conversion of soil potash from the nonreplaceable to the replaceable form. Jour. Amer. Soc. Agron., 27:437–445. 1935.
2. BEAR, FIRMAN E., PRINCE, ARTHUR L., and MALCOLM, JOHN L. The potassium-supplying powers of 20 New Jersey soils. Soil Sci., 58:139–150. 1944.
3. BRAY, R. H., and DETURK, E. E. The release of potassium from non-replaceable forms in Illinois soils. Soil Sci. Amer. Proc., 3:101–106. 1939.
4. COLWELL, W. E. A biological method for determining the relative boron contents of soils. Soil Sci., 56:71–94. 1943.
5. FRAPS, G. S. Relation of the water-soluble potash, the replaceable, and acid-soluble potash to the potash removed by crops in pot experiments. Tex. Agr. Exp. Sta. Bul. 391. 1929.

6. HOAGLAND, D. R., and MARTIN, J. G. Absorption of potassium by plants in relation to replaceable, and soil solution potassium. Soil Sci., 36:1–33. 1933.
7. PEECH, MICHAEL. Determination of exchangeable bases in soils. Rapid microchemical methods. Ind. and Eng. Chem., Anal. Ed., 13:436–441. 1941.
8. WILCOX, L. V. Determination of potassium by means of an aqueous solution of trisodium cobaltinitrite in the presence of nitric acid. Ind. and Eng. Chem., Anal. Ed., 9:136–138. 1937.

EFFECT OF SODIUM NITRATE APPLIED AT DIFFERENT PERIODS OF THE GROWING SEASON ON THE YIELD, COMPOSITION, AND QUALITY OF WHEAT[1]

JEHIEL DAVIDSON AND RUTH BUCHANAN[2]

A SERIES of experiments beginning in 1916 (4, 5)[3] showed that nitrates, as well as ammonium salts, increased the yield of wheat when applied at an early period of the vegetative stage, increased the protein content, and prevented "yellow berry" when applied at the time of heading, but had no effect either on yield or composition when applied at the "milk stage". Similar results were obtained by Moertlbauer (10), Gericke (7), Neidig and Synder (11), and, more recently, by Selke (12).

In a later experiment (3) carried out at College Park, Md., it was shown that when the vegetative period (from resumption of growth in the spring until heading time) was divided into three arbitrary subperiods, the increase in yield, due to the application of nitrates, was directly related to the earliness of the respective subperiod, while the protein content of the grain was inversely related.

Results are reported here for experiments in which the entire wheat-growing season was divided into 14 periods, extending from the time of planting to the advanced "milk stage."

EXPERIMENTAL PROCEDURE

The experiments were carried out on the Arlington Experimental Farm, Arlington, Va., in the crop year 1922–23. The size of the plots was 1/40 acre. The seed used was "Purple Straw", a soft red winter wheat variety. Eight pounds of sodium nitrate (at the rate of 320 pounds per acre) were applied to each plot but on different dates. The first fall applications were made after the crop was up. The control plots received no fertilizer treatment. The wheat headed out between May 25 and 29. The experiments were run in duplicate series.

RESULTS

The yields of the entire crops (grain and straw) and of the grain, as well as the ratio of grain to straw, expressed as the percentage of grain in the entire crop, are given in Table 1.

In series 1, while there is considerable variation in yield, the differences could not be attributed with certainty to the sodium nitrate applications, owing to the high yields obtained from the control plots. In series 2 the early applications of sodium nitrate resulted in an increase of the entire crop (grain and straw) and, if the second control plot be disregarded, also in an increase in the yield of grain. The differences in the yield in series 1 may have been due to differences in the soil, as many plots or sections on the Arlington Farm lacked uniformity owing to artificial origin and to treatment received in pre-

[1]Contribution from the Division of Cereal Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture. Received for publication April 3, 1945.

[2]Formerly Associate Chemist, Bureau of Plant Industry, Soils, and Agricultural Engineering and Bureau of Chemistry; and formerly Junior Chemist, Bureau of Chemistry, respectively.

[3]Numbers in parenthesis refer to "Literature Cited", p. 725.

TABLE 1.—*Yields and percentage of grain in entire crop.**

Date of application	Series 1			Series 2		
	Entire crop, lbs.	Grain, lbs.	Percentage of grain	Entire crop, lbs.	Grain, lbs.	Percentage of grain
Oct. 17	164.0	49.0	29.89	203.0	46.2	22.75
Nov. 3	178.0	52.5	29.41	195.0	52.5	26.92
Nov. 18	177.0	52.5	29.66	184.5	48.5	26.28
Dec. 21	174.5	51.0	29.33	180.0	47.7	26.50
Mar. 28	173.0	45.5	26.30	195.0	55.0	28.20
Apr. 18	122.5	40.0	32.65	174.5	55.0	31.52
May 2	112.5	35.0	31.10	165.0	48.0	29.09
May 10	115.0	35.0	30.43	144.5	42.5	29.41
May 17	119.5	36.5	30.54	152.0	42.0	27.63
May 25	96.0	30.5	31.77	158.5	43.0	27.12
May 29	99.0	32.5	32.83	152.0	43.5	28.64
June 4	116.5	35.5	30.47	144.0	41.5	28.82
June 12	153.0	42.0	27.45	130.0	38.5	29.61
June 16	174.5	46.0	26.36	130.0	40.7	31.30
Control	172.0	45.0	26.16	139.0	40.7	29.28
Control	171.5	45.0	26.24	154.0	46.0	29.87

*Grain and straw.

vious diversified experiments. It was sometimes difficult to trace completely the history of certain sections. Further, some of the sections did not respond to mineral nitrogen treatment with respect to yield. The section alloted for these experiments evidently belonged partly to this class.

The protein content, sulfur content, weight per bushel, and weight per thousand kernels are given in Table 2.

It has been assumed that nitrogen applied at the early stages of the growing crop is consumed in making vegetative growth and therefore does not greatly affect the protein content of the grain. Headden (8) applied sodium nitrate at the time of planting under conditions where there was no response in yield and obtained a marked increase in the protein content of the grain, presumably because the nitrogen not having been used in making vegetative growth was later used by the plants to make protein. In series 1 of the present experiments, however, like in those of Headden, there was little, if any, consistent yield response to nitrogen, but the early applications did not result in any increase in the protein content of the grain. This is the more significant in view of the relatively large applications of sodium nitrate made. It brings out the fact that inorganic nitrogen applied to soils on which the crop does not respond to it in yield is, under certain conditions, largely lost. The different response in protein to the early applications of nitrogen in series 1 of these experiments carried out at Arlington and in those of Headdon carried out in Colorado is probably due to a difference in the amount of nitrates lost by leaching and through other causes under the two sets of climatic conditions.

The protein content of grain in both series was increased consistently as in the case of the College Park experiments (3), with the

TABLE 2.—*Protein and sulfur content of grain and weight per bushel and weight per 1,000 kernels.*

Date of application of sodium nitrate	Series 1				Series 2			
	Protein (N×5.7), %	Sulfur, %	Weight per bushel, lbs.	Weight per 1,000 kernels, grams	Protein (N×5.7), %	Sulfur, %	Weight per bushel, lbs.	Weight per 1,000 kernels, grams
Oct. 17	10.26	0.145	60.5	27.36	11.91	0.153	58.5	25.44
Nov. 3	10.54	0.143	60.5	27.04	12.65	0.160	59.5	26.28
Nov. 18	10.54	0.146	61.0	27.44	12.20	0.165	59.7	24.64
Dec. 21	10.94	0.157	60.2	26.24	12.76	0.154	59.7	25.60
Mar. 28	12.25	0.172	59.5	25.64	13.28	0.163	60.0	24.56
Apr. 18	13.28	0.176	59.5	26.56	14.19	0.185	60.7	26.52
May 2	13.96	0.169	60.0	27.84	15.33	0.176	60.0	26.84
May 10	12.48	0.155	60.7	28.52	15.62	0.196	61.0	27.28
May 17	14.87	0.167	60.0	27.08	15.27	0.171	60.5	27.20
May 25	15.90	0.183	60.7	27.36	16.13	0.183	59.6	26.40
May 29	16.13	0.181	60.1	27.32	16.47	0.176	60.5	25.44
June 4	15.10	0.166	60.2	27.36	15.96	0.178	60.0	26.68
June 12	11.97	0.154	59.5	26.12	12.71	0.155	60.0	27.52
June 16	11.28	0.156	59.7	26.00	11.28	0.158	57.0	27.56
Control	10.31	0.147	60.0	24.84	11.51	0.145	59.0	27.24
Control	10.77	0.159	59.0	25.24	11.51	0.142	59.0	27.60

lateness of application up to a certain point when it declined again approaching that of the controls. The highest protein content obtained for the latest applications before the decline is about 50% above the protein content of the controls.

The sulfur content of the grain was determined by the magnesium nitrate method (1). The results described, in a general way, the same (imaginary) curve as the protein results, the highest sulfur content coinciding, as a rule, with the highest protein content. This would tend to indicate that the nitrogen increment produced by the application of nitrogenous fertilizers at certain periods of growth is partly or wholly in the form of true proteins in view of the fact that cystine, which is the principal sulfur-carrying amino acids, is an integral part of all wheat proteins. The increase in sulfur, however, is not proportional to the increase in protein. Wheat proteins vary in their cystine content and it is possible that the ratio of protein distribution in the high protein wheat obtained in these experiments favored the proteins of a low cystine content, as glutenin and globulin. It is further possible that the increase in nitrogen was not all in the form of protein nitrogen.

The weights per bushel and per 1,000 kernels are given in the same table with the protein and sulfur contents. The results show lack of correlation between these two factors and the protein content of wheat. This is at variance with the view held by many that high protein in wheat is associated with a low weight per 1,000 kernels and a low weight per bushel. Similar lack of correlation between these factors was shown in an earlier paper by Davidson and LeClerc (5)

in which the question was discussed more fully. A like conclusion was reached by Bailey and Hendel (2) while correlating the weight per 1,000 kernels and the protein content of middlings flour for a number of years.

DISCUSSION

The results of these experiments corroborate and extend the previous results obtained by the senior author (3, 4, 5, 6), as well as those of other investigators who have worked along the same lines. They bring out the fact that late applications (up to a certain date) of inorganic nitrogen result in an increased nitrogen content of the wheat regardless of whether the soil responds to this treatment or not with respect to yield. That at least part of this nitrogen increase is in the form of protein is indicated by the fact that the increase in nitrogen content is correlated with an increase in sulfur.

Wheat naturally rich in protein yields a "strong" flour which gives a bread of superior quality. Bread made from wheat in which the nitrogen content has been increased by applying sodium nitrate at heading time also exhibited a larger volume and superior quality to bread made from the control wheat grown in the same field (6). This may also be taken as indirect evidence that the nitrogen increment is partially or wholly in the form of true proteins.

The principles disclosed in these experiments show that the use of fertilizer has to be studied from a number of angles. They offer a plausible explanation of the effect of climate on the protein content of wheat as found by Le Clerc and Leavitt (9) and by Shaw and Walter (12). In the light of these experiments, climates which yield a high protein wheat probably favor a relatively high nitrate concentration in the soil at the time of heading.

Moreover, the possibility remains that the application of these principles to some cultivated crops may prove expedient both from the standpoint of their present methods of cultivation and economic returns.

SUMMARY

Applications of sodium nitrate to wheat were made at a number of periods during the growing season under conditions under which no definite response with respect to yield was obtained.

The results show that (a) the protein content increased gradually the nearer the applications were made to the time of heading and declined again on the plots on which the applications were made after this stage of growth, (b) that the sulfur content followed in a general way the same course as the protein content; and (c) that there was no correlation between the protein content and the weight per bushel and weight per 1,000 kernels.

LITERATURE CITED

1. Association of Official Agricultural Chemists. Official and Tentative Methods of Analysis. 1930.
2. Bailey, C. H., and Hendel, Julius. Correlation of wheat kernel plumpness and protein content. Jour. Amer. Soc. Agron., 15:345–350. 1923.

3. DAVIDSON, JEHIEL. The effect of nitrates applied at different stages of growth on the yield, composition and quality of wheat. Jour. Amer. Soc. Agron., 14:118–122. 1922.

4. ————, and LECLERC, J. A. The effect of sodium nitrate applied at different stages of growth on the yield, composition and quality of wheat. Jour. Amer. Soc. Agron., 9:145–154, 1917; 10:193–198. 1918.

5. ————, and LECLERC, J. A. Effect of various inorganic nitrogen compounds applied at different stages of growth on the yield, composition and quality of wheat. Jour. Agr. Res., 23:55–68. 1923.

6. ————, and SHOLLENBERGER, J. H. Effect of sodium nitrate applied at different stages of growth on the baking quality of flour. Cereal Chem., 3:137–143. 1926.

7. GERICKE, W. F. Differences effected in the protein content of grain by applications of nitrogen made at different growing periods of plants. Soil Sci., 14:103–109. 1922.

8. HEADDEN, W. P. A study of Colorado wheat. Colo. Agr. Exp. Sta. Bul. 219. 1916.

9. LECLERC, J. A., and LEAVITT, SHERMAN. Tri-local experiments on the influence of environment on the composition of wheat. U. S. D. A. Bur. Chem. Bul. 128. 1910.

10. MOERTLBAUER, F. Ueber den Einfluss verschiedenzeitiger Saltpeterdugung auf die Mehlkorperstrucktur und den Proteingehalt des Weizens Illus. Landwirtschaftliche Zeitung, 30:903–904. 1910.

11. NEIDIG, R. E., and SNYDER, R. S. The effect of available nitrogen on the protein content and yield of wheat. Idaho Agr. Exp. Sta. Res. Bul. 1. 1922.

12. SELKE, W. Die Wirkung Zusatzlicher später Stickstoffgaben auf Ertrag und qulaität der Ernteproducte. Bodenkunde und Pflanzenernährung, 20:1–49. 1940.

13. SHAW, G. W., and WALTER, E. C. A progress report upon soil and climatic factors influencing the composition of wheat. Calif. Agr. Exp. Sta. Bul. 216:549–574. 1911.

EFFECT OF THE TEMPERATURE OF THE ROOT ENVIRONMENT ON GROWTH OF SOYBEAN PLANTS[1]

E. B. EARLEY AND J. L. CARTTER[2]

ROOT temperature as a factor in the growth of soybean plants has not been investigated as far as the writers are able to learn from a review of the literature. However, attention has been directed to this problem by several investigators for other species of plants. Bailey and Jones (1)[3] showed that the average height and average total linear growth of blueberries increased with increasing root temperatures from 13° to 32° C, with the average total linear growth somewhat more closely correlated with the temperature treatments than the average height. No dry weight data of plants were given. Batjer, *et al.* (2) presented data which indicated that a root temperature of 7° C was less favorable for the growth of young apple trees than the average greenhouse temperature of approximately 24° C. The work of Kincaid and Gratz (3) indicates that the temperature of the soil is an important factor in the growth of tobacco. Their results showed that the minimum soil temperature for top development was about 9° C, the maximum about 40° C, and the optimal range from about 24½° to 32° C. A few data presented by Stuckey (4) show that the dry weight production of colonial bent grass was favored by a soil temperature of 16° C as compared to 10° or 27° C. According to Wort (5) Marquis wheat gave a gradually decreasing dry weight yield of tops and roots with a rise in soil temperature from 22° to 42° C.

These studies show that the temperature of the root environment plays an important role in plant development and consequently unless root temperature is properly adjusted to the aerial environment, it may limit or cancel the response of plants to other factors under investigation. Therefore, it was thought advisable to ascertain the influence of root temperature on the growth of soybean plants in order that this factor may be controlled in other experimental work.

MATERIALS AND METHODS

A view of the apparatus used in maintaining different temperatures around the roots of the soybean plants in this investigation is shown in Fig. 1. Each of the seven box-like units is equipped with heating and cooling coils operated thermostatically. Electrical space heaters provide heat. A common refrigerating compressor supplies the cooling for the units, the refrigerant for each box being controlled by a solenoid valve in the liquid line ahead of the expansion valve for that box. A double pole thermostat with an adjustable differential maintains

[1]A publication by the U. S. Regional Soybean Laboratory, a cooperative organization participated in by the Bureau of Plant Industry, Soils and Agricultural Engineering, Agricultural Research Administration, and the agricultural experiment stations of Alabama, Arkansas, Florida, Georgia, Illinois, Indiana, Iowa, Kansas, Louisiana, Michigan, Minnesota, Mississippi, Missouri, Nebraska, North Carolina, North Dakota, Ohio, Oklahoma, South Carolina, South Dakota, Tennessee, Texas, Virginia, and Wisconsin. Received for publication April 3, 1945.

[2]Assistant Agronomist and Senior Agronomist, respectively, U. S. Regional Soybean Laboratory, Urbana, Ill.

[3]Figures in parenthesis refer to "Literature Cited", p. 735.

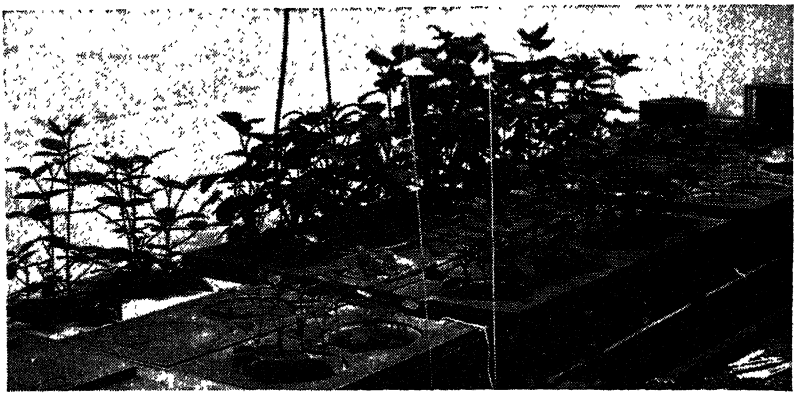

FIG. 1.—Apparatus for maintaining different temperatures around the roots of soybean plants.

the desired temperature in each unit by supplying refrigerant or heat as needed. A small electric fan operating continuously circulates air in the boxes to maintain even temperature around the solution bottles and gravel culture jars. Some water is maintained in the bottom of each box so that the air above remains nearly saturated. For the fourth and fifth experimental runs, the tops of the culture jars were covered and sealed and a connecting tube extended from the top of each jar to the inside of the temperature box. This arrangement is illustrated in Fig. 2. During the subsequent draining back after each automatic flooding of the gravel, the culture jars were filled with saturated air at the controlled temperature. This modification of the equipment made possible a more even control of root temperature. The soybean plants were grown in 2-gallon glazed earthenware jars filled to within 3 inches of the top with gravel. A river gravel was used for the first run, and acid-washed crushed quartz about 3 to 6 mm in size was used in succeeding experiments.

Each pair of jars was flooded with nutrient solution four times daily, 8 a.m., 11 a.m., 2 p.m., and 5 p.m., from a 12-liter pyrex bottle by means of subirrigation. Distilled water was used at all times. Loss of water through evaporation and transpiration was replaced twice weekly. In experiments 1, 2, and 3 the water added to the jars was of room temperature (about 21° C); however, the water was added just before flooding the gravel with nutrient solution. This method reduced to a minimum the temperature change around the roots. In experiments 4 and 5 the temperature of the water was adjusted to that of the nutrient solution before being added to the jars.

Two or three seeds were planted per hill and thinned to one plant at emergence. Supplementary light was used in experiments 3, 4, and 5, principally to prevent the plants from blooming abnormally early, as they ordinarily do under the short days of fall and winter. No supplementary light was required for experiments 1 and 2 which were conducted during the long days of summer.

The nutrient solution used in this work was as follows:

Elements	N	P	K	Ca	Mg	S	Cl
Parts per million	140	62	195	220	73	128	71
Millimoles	10	2	5	5.5	3	4	2

Salts	Moles
KH_2PO_4	0.002
KNO_3	0.003
$Ca(NO_3)_2.4H_2O$	0.0035
$CaSO_4.2H_2O$	0.001
$CaCl_2.2H_2O$	0.001
$MgSO_4.7H_2O$	0.003

Minor elements: 5 p.p.m. of Mn as $MnCl_2.4H_2O$; 0.5 p.p.m. of B as crystalline H_3BO_3; and 0.05 p.p.m. of Cu as $CuSO_4.5H_2O$. $FeCl_3.6H_2O$ added as needed.

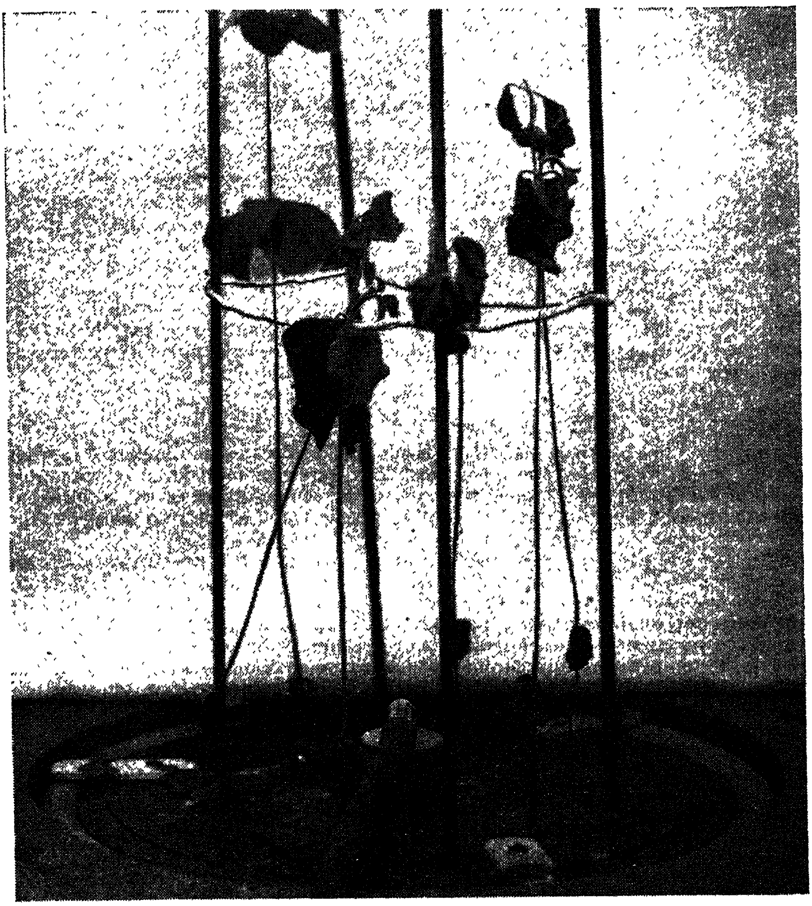

FIG. 2.—Soybean plants growing in gravel culture in a 2-gallon jar sealed to prevent fluctuation of root temperature and loss of water through surface evaporation. This photograph of plants with root environment held at 2° C illustrates the deleterious effect of extremely low root temperature.

EXPERIMENT 1

On May 6, 1938, four hills of Hudson Manchu soybeans were planted in each of eight jars containing Muscatine river gravel. The plants were grown for 27 days under uniform conditions. For the next 22 days, from June 2 to June 24, the temperature of the root environment of the four units used, containing two jars each, was 7°, 17°, 27°, and 37° C, respectively. Temperature records of the greenhouse were taken for only the last week of this experiment. The mean temperature was 34° C during the day and 22° C during the night. The photoperiod was that of natural day length with no supplementary light. The light intensity was high as would be expected for this time of the year.

EXPERIMENT 2

On July 22, 1939, five hills of Dunfield seed were planted in each of four jars in six units of the root temperature apparatus. The plants were grown under uniform conditions from planting to July 31, and for the next 22 days, the tem-

perature of the root environment of the six units was maintained at 7°, 17°, 22°, 27°, 32°, and 37° C, respectively. Temperature records of the greenhouse were taken from July 24 through August 14. The mean temperature was 30° C during the day and 21° C during the night. No supplementary light was needed since the natural photoperiod was long and the light intensity high.

EXPERIMENT 3

On September 6, 1939, five hills of Dunfield seed were planted in each of four jars in each of six units of the root temperature apparatus. The plants were grown under uniform conditions from planting to September 13. For the next 27 days, one of each of the six root temperature units was maintained at 7°, 17°, 22°, 27°, 32°, and 37° C, respectively. No temperature records were taken of the greenhouse during this experiment; however, the day temperature was about 27° C and the night temperature about 21° C. A photoperiod of 18 hours was maintained during this experiment. During 9 hours of the photoperiod, supplementary light was furnished for each unit by a 750-watt Mazda bulb. The light intensity was somewhat lower than for experiments 1 and 2 but still of moderate intensity.

EXPERIMENT 4

On November 21, 1939, six hills of Hudson Manchu seed were planted in each of four jars in six units of the apparatus. They were germinated and grown under uniform conditions until December 1 when the temperatures of the units were adjusted to 2°, 7°, 12°, 17°, 22°, and 27° C, respectively. These root temperatures were maintained until January 8, a period of 39 days.

For this and the next experimental run, the loss of water by evaporation from the surface of the gravel was prevented by allowing the plants to grow through holes in a circular board placing a tuft of cotton around each stem and sealing the entire top of the jar with a paraffin-vaseline mixture as illustrated in Fig. 2. From the center hole of the circular board a rubber tube was conducted into the box of the temperature unit through which exchange of air took place during the flooding process. This technic helped to maintain a more uniform temperature around the root system. Some water was kept in the bottom of each unit to maintain saturation of the air and minimize the loss of water from the jars through the air exchange tube.

For this run, the mean temperature of the greenhouse was 24° C during the day and 21° C during the night. No supplementary light was used directly over these plants during this period but some light was received from an adjacent bench. The photoperiod to which these plants were subjected was about 13½ hours. The light intensity was rather low as might be expected at this time of the year, but due to the supplementary light from the adjacent bench was higher on the north half of each unit than on the south half.

EXPERIMENT 5

On March 22, 1940, six hills of Hudson Manchu soybeans were planted in each of four jars in seven root temperature boxes, a special high temperature unit having been added for this run. The plants grew at uniform conditions until April 4. At that time the jars were sealed as shown in Fig. 2, and the root temperature treatments of 7°, 12°, 17°, 22°, 27°, 32°, and 37° C were started and maintained until the plants were harvested on May 1, 27 days later.

The method of sealing the jars, adding water, and using air of proper temperature for subirrigation was similar to that used in experiment 4. The mean temperature of the greenhouse at the time of the experiment was 27° C during the day and 23° C during the night. The plants received uniform supplementary light from 1000-watt bipost Mazda lamps. The photoperiod averaged about 15 hours of which about 7 were supplementary light. The light intensity was rather high during this experiment.

EXPERIMENTAL RESULTS AND DISCUSSION

The dry weight production of tops by Dunfield and Hudson Manchu soybean plants as given in Table 1 is shown to be markedly

affected by the temperature of the environment of the root system. Table 1 also gives an analysis of variance of the yield of top growth from experiments 2, 3, and 5 and shows that the variations in yield of dry plant tissue due to temperature treatment were highly significant. These differences in growth are graphically shown in Fig. 3, upper left, for all five experiments. Fig. 4 shows the appearance of the plants in the first experiment 22 days after the root temperature treatments were started.

TABLE 1.—*Influence of root temperature on dry weight production of soybean tops for five experiments with analysis of variance on data from experiments 2, 3, and 5.*

Root temperature, °C	Mean yield per plant (grams) for experiment				
	1	2	3	4	5
2	—	—	—	0.19	—
7	3.16	0.75	0.71	0.56	0.69
12	—	—	—	0.85	1.96
17	4.58	1.59	1.58	0.89	3.02
22	—	1.99	1.60	1.09	3.34
27	8.62	2.40	1.75	1.05	3.58
32	—	1.50	1.32	—	3.95
37	5.56	1.27	0.88	—	1.63

Analysis of Variance

Variation due to:	Degrees of freedom	Mean square	F
Runs..................	2	3.2733	
Treatments..............	5	1.5492	5.7**
Error (runs × treatments)	10	0.2716	

**Highly significant "F" value.

The magnitude of the difference in yield of dry material among the root temperature treatments for the five experiments was found to depend to a large degree upon a relationship between light intensity of the photoperiod and the temperature of the root system. For example, consider experiments 4 and 5 where all factors were fairly uniform except the light intensity. In experiment 4 where the light intensity was relatively low throughout the experiment, yield of tops increased very slightly with increasing root temperature from 7° to 27° C, light intensity being the limiting factor. In experiment 5, with high light intensity, dry weight of tops increased rapidly from 7° to 17° C, continued to show steady gains to 32° C, and declined rapidly at 37° C. These latter results are very similar to those reported by Kincaid and Gratz (3) for tobacco.

It was further learned from these root temperature experiments that, within the limits studied, irrespective of the light intensity or the time of year during which the experiments were conducted, root temperatures as low as 12° C and as high as 37° C restricted the production of dry weight material. In four of the five experiments, 17° C root temperature was too cold for maximum plant development. In experiments 1, 2, and 5, which received high light intensity,

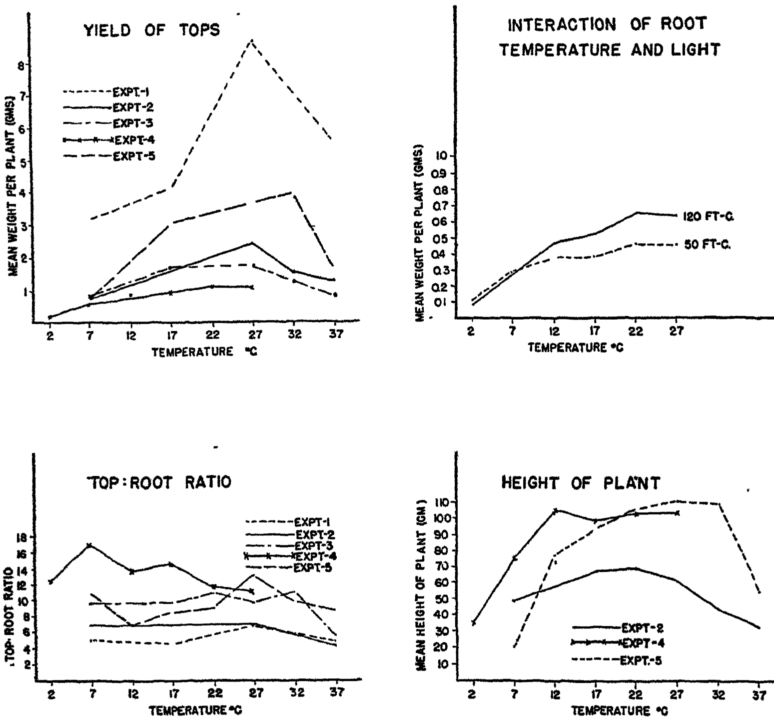

FIG. 3.—Influence of root temperature on the growth of soybean plants.

a root temperature of 22° C somewhat limited growth whereas in experiments 3 and 4 (medium to low light intensity), this root temperature favored maximum production of dry material.

An interesting relationship of light intensity and root temperature to soybean growth was observed in experiment 4. In this case, 5 hours of reflected supplementary light from an adjacent experiment fell upon the north tier of plants more strongly than upon the south tier of plants. As measured by a Weston photometer the plants in the north tier received a supplementary light intensity of 120-foot candles while those in the south tier received an intensity of only 50-foot candles. The intensity of natural light during the remainder of the photoperiod, 8½ hours, was considerably lower than it was in the other four experiments, being about 350-foot candles on clear days. It was of somewhat higher intensity than the supplementary light, however, and was uniform over both tiers of plants.

The yield data from this experiment, shown graphically in Fig. 3, upper right, indicate that with a low light intensity, as occurs during the winter months, plant growth responded to increasing root temperatures from 2° to 22° C but gave no additional response when the root temperature was raised to 27° C. However, the interesting point here is the manner in which the soybean plants growing at different supplementary light intensities reacted to the various root tempera-

FIG. 4.—Hudson Manchu soybean plants grown in root temperature control apparatus. These temperatures were, from left to right, 7°, 17°, 27°, and 37° C.

tures. When grown at root temperatures from 12° to 22° C, the plants produced more top growth under the higher supplementary light intensity, whereas below 12° C, namely, 7° and 2° C, the plants produced slightly greater growth under the lower supplementary light intensity. The appearance of the plants in the jars gave somewhat clearer views of this difference than the dry weight data indicate. From these results, one might expect an additional increase in dry weight production and plant growth at 2° and 7° C and less damage from the lack of water absorption if the intensity of the photoperiod was further reduced. Such would not be true at any of the higher root temperatures since at 12° C or above, 120-foot candles of supplementary light increased dry weight production over the lower light intensity of 50-foot candles. With their root systems at 7° C or below, the plants suffered from inability to absorb sufficient water from the gravel culture to satisfy their requirements, as evidenced by wilting on clear days (Fig. 2). The study of mineral and water intake in experiments 4 and 5 will be presented in a separate paper.

ROOT TEMPERATURE AND ROOT GROWTH

The temperature of the root environment influenced dry weight production of roots to a somewhat lesser degree than was true of the tops. This is indicated in Table 2 by the "F" value of only 3.37 which is somewhat below the value necessary for significance. However, as shown in Table 2, root growth in a general way tended to show an increase with increasing root temperature from 2° to about 27° C.

TABLE 2.—*Influence of root temperature on dry weight production of soybean roots for five experiments with analysis of variance on data from experiments 2, 3, and 5.*

Root temperature, °C	Mean weight per plant (grams) for experiment				
	1	2	3	4	5
2	—	—	—	0.02	—
7	0.62	0.11	0.07	0.03	0.06
12	—	—	—	0.06	0.29
17	0.99	0.24	0.16	0.06	0.36
22	—	0.29	0.14	0.09	0.31
27	1.35	0.36	0.18	0.10	0.27
32	—	0.26	0.12	—	0.41
37	1.16	0.31	0.15	—	0.19

Analysis of Variance

Variation due to:	Degrees of freedom	Mean square	F
Runs.	2	0.0326	
Treatments.	5	0.0155	3.37
Error (runs × treatments)	10	0.0046	

It was also observed in these studies that the intensity of the light was the controlling factor in determining the magnitude of response of root development to each increment of root temperature.

ROOT TEMPERATURE AND TOP: ROOT RATIOS

The influence of root temperature on the ratio of tops and roots may be observed for each of the five experiments in Fig. 3, lower left. These data show a surprisingly close relationship between production of tops and roots over a wide range of root temperature during the first 30 to 45 days of plant growth. The top: root ratios fluctuated from about 5 in experiment 1 to about 13 in experiment 4. The ratios seem to be determined predominantly by the light intensity since the biggest difference in the aerial environment between experiment 1 with a top: root ratio about 5 and experiment 4 with a ratio about 13 was the intensity of the photoperiod. As a matter of fact, the uniform increase in top: root ratios from experiment 1 to experiment 4 is in inverse relationship to the intensity of the photoperiod. An examination of the dry weight data shows that this increasing top: root ratio with decreasing light intensity is caused by a larger proportional reduction in root growth than in top growth. The analysis of variance of the data shows a nonsignificant difference among top: root ratios due to temperature treatments.

ROOT TEMPERATURE AND PLANT HEIGHT

The height data from experiments 2, 4, and 5 are given graphically in Fig. 3, lower right. In general, the height of the plants increased with root temperatures from 2° to about 17° C, remained fairly uniform from 17° to about 27° C, and decreased at 37° C. It appears

that the temperature of the root environment should be from about 22° to about 27° C in order to insure the maximum height of soybean plants.

SUMMARY

The data obtained from this investigation indicate that irrespective of the light intensity or the time of year during which the experiments were conducted, root temperatures as low as 12° C and as high as 37° C restricted production of dry weight of Dunfield and Manchu soybean plants. In four of the five experiments, root temperature as low as 17° C prevented maximum plant development. Root temperatures from about 22° to about 27° C appear to be most favorable for maximum dry weight production of top and roots when soybean plants are grown under a wide variety of aerial environmental conditions in the greenhouse.

A rather close relationship was found between the top:root ratios throughout the temperature treatments, when the experiments are considered individually. However, when the experiments are considered collectively, it was found that the magnitude of the ratios apparently was determined largely by the light intensity of the photoperiod. The low top:root ratios were obtained under high light intensity conditions and the high ratios were obtained under low light intensity conditions.

In general, the height of the soybean plants increased with increasing root temperature from 2° to about 17° C, remained uniform from about 17° to about 27° C, and decreased rapidly at 37° C.

LITERATURE CITED

1. BAILEY, J. S., and JONES, T. H. The effect of soil temperature on the growth of cultivated blueberry bushes. Proc. Amer. Soc. Hort. Sci., 38:462–464. 1941.
2. BATJER, L. P., MAGNESS, J. R., and REGEIMBAL, L. O. The effect of root temperature on growth and nitrogen intake of apple trees. Proc. Amer. Soc. Hort. Sci., 37:11–18. 1940.
3. KINCAID, R. R., and GRATZ, L. O. Soil temperature studies on Florida cigar-wrapper tobacco. Jour. Agr. Res., 51:441–449. 1935.
4. STUCKEY, IRENE H. Influence of soil temperature on the development of colonial bent grass. Plant Phys., 17:116–122. 1942.
5. WORT, D. J. Soil temperature and growth of marquis wheat. Plant Phys., 15:335–342. 1940.

NUMBERING AND NOTE-TAKING SYSTEMS FOR USE IN THE IMPROVEMENT OF FORAGE CROPS[1]

L. C. NEWELL AND H. M. TYSDAL[2]

THE widespread development in the breeding of cross-pollinated perennial forage crops has resulted in considerable attention being placed upon breeding methods. Associated problems are those of applying a satisfactory numbering system in the improvement of such plant materials and of evaluating the resulting selections, strains, and varieties. Where an investigator is carrying on improvement with one or more kinds of plants, it is desirable that a single logical system of numbering be used. Such a system may facilitate the selection and use of suitable breeding procedures. A basic plan for numbering selections of plant and seed material which also includes recognition of breeding methods in their identification has been applied to the breeding of grasses and legumes at the Nebraska Agricultural Experiment Station. A numerical system of taking notes has also been adopted.

The numbering and note-taking systems which were developed over a period of years have been successfully used by the authors and in part by workers at other stations. Because of the broad application of these plans and their proved usefulness, it has been thought desirable to present them in their entirety. Although something of the philosophies of crop improvement in general are herewith implied in the numbering system, it is not intended that these be the purpose of this paper. The presentation of the plan is given rather as an example of how such a numbering system might be used in plant improvement. The plan is considered flexible enough to be adapted to the breeding of any crop.

THE NUMBERING SYSTEM

The work of keeping track of the changing genetic composition of plant material with the employment of different breeding procedures is difficult. The problems of breeding normally cross-pollinated plants are more complex than those for plants which are normally self-pollinated. With cross-pollination only the maternal side of the inheritance can be followed unless controls of pollination are established. These controls can be diverse and unless some system is used for their easy recognition in the records of the plant breeder, he is soon lost in a maze of notes concerning his selections.

[1]Contribution from the Division of Forage Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture, and the Department of Agronomy, Nebraska Agricultural Experiment Station, Lincoln, Nebr., cooperating. Published with the approval of the Director of the Nebraska Agricultural Experiment Station as Journal Series Paper No. 371. Received for publication April 9, 1945.

[2]Associate Agronomist and Senior Agronomist, respectively, Division of Forage Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration. The authors are indebted to Mr. Bliss H. Crandall, Associate Agronomist, Division of Forage Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering, for helpful comments and suggestions made in the preparation of the manuscript.

A selection of a perennial cross-fertile plant may one year produce self-pollinated seed and in the same or following year produce cross-pollinated seed. During the same or succeeding years the mother plant selection or its clones may continue to produce seed under a variety of conditions favoring self- or cross-pollination. In any one year the resulting seed lots from the mother plant, its clones, or from the advanced generation plantings of the selections may differ in genetic composition. The genetic composition varies in proportion to the degree of cross-fertility of the selection and with respect to the mode of pollination involved which determines the extent of cross-pollination that may occur.

The pedigree system of numbering is a commonly used system for tracing generations of plant material. In this system the line of descent from a particular selection is traced through several generations by a series of plant numbers separated by letters, parentheses, or dashes, etc. (3).[3] In the widely known Minnesota system, the differentiation between selections, crosses, and new introductions is also included in the identification (4). The pedigree system lends itself best to selfed-line breeding and hybridization methods but is inadequate in its description of naturally cross-pollinated plant materials. Because of the lengthy numbers which are soon involved with the pedigree system, many workers prefer to renumber their selections each year, tracing the line of descent through the records of previous numbers. Other workers use the row and plant number of field locations for identification. New numbers are given each year with source records to show the previous numbering. With vegetative propagation of plants identical material might be planted in different rows in the same and in different years, thus making the identification of a selection by row and plant numbering rather confusing. These systems are difficult if applied to perennials because of such duplications encountered and the difficulties of associating new numbers with plant materials every year.

The numerical identification of a selection should be short; it should be one easily distinguished and remembered; it should express as much as possible about the selection without the necessity of writing long explanations on tags or on stake labels to explain the ramifications of breeding methods previously employed.

In the system proposed for biennial and perennial cross-pollinated species, at least three ideas are incorporated into the identification number. These are the year of plant selection or seed harvest, the treatment involved in the procedure or the conditions under which seed was produced, and the serial identification of the selection. The system involves the use of an annual inventory of plant and seed selections, definite objectives in relation to breeding methods, and recorded descriptions of plant or seed materials with their previous history identified by serial numbers in accession books. Planting plan records carry columns for source of plant material in order to associate newly applied numbers to older numbers as is done in other systems. Records are kept in duplicate for office and field use to avoid the danger of loss of information.

[3]Figures in parenthesis refer to "Literature Cited", p. 748.

The application of the system to an actual breeding project is not difficult. Selections are serially numbered over a period of years with descriptions of the plant or seed material appearing in the accession books. The year of selection and the breeding method treatment involved in the production of seed are designated by numbers prefixed to the serial number. The year of selection appears first. For brevity, it is the last figure in the applicable calendar year. For example, a single plant selected in 1943 might be numbered 3–20 and its description recorded in the accession book under the newly selected serial number 20. A treatment index number is inserted as a second figure in the identification to designate the pollination conditions or the breeding method involved in the production of the seed. For example, referring to Table 1 for interpretation of treatment index numbers, the identification number 31–20 (index No. 1) may be applied to selfed seed produced in 1943 from the selected plant. The number 39–20 would be used to designate open-pollinated seed produced the same year from the same plant (index No. 9). The record of these seed selections in the seed inventory of that year would automatically refer to the description of the mother plant in the accession books. The selfed and open-pollinated progenies grown from this single plant selection would be tested in 1944 under these numbers. In addition, the mother plant clonally propagated under its assigned serial number could be tested or used in more complex breeding procedures. Since no treatment index referring to the seed which produced this plant can be used with this new serial number, the clones would be given the designation 30–20 (index No. 0). This index number indicates no advance in generation as implied by other index numbers referring to seed, and it would be dropped out of any designation later to be applied to seed harvested from these clones.

Combinations of treatment index numbers may be used to identify two or more generations of a given selection before reselection and renumbering take place. A newly added treatment index number always follows the latest year designation, the former year designations being dropped from the identification. For example, in 1944, seed produced by the open-pollination of the open-pollinated progeny, 39–20, would be numbered 499–20 if in tests with other progenies with which it might cross (index No. 9); or it would be numbered 439–20 if isolated and an advanced generation of seed is obtained without reselection (index No. 3). Similarly, seed produced by the open-pollination of the selfed progeny, 31–20, would be 491–20 or 431–20, as the case might be. If it is desirable to continue inbreeding with a selection of plants, the index numbers 1 or 2 would be used. Seed produced by selfing or sibbing in this generation could be indicated by pedigrees of individual plants. Selfed seed from the plant 31–20–1 would be harvested in 1944 as 411–20–1, etc. (or the plant could be given a new number, such as 30, and its selfed seed numbered 41–30, etc.) The pedigree numbering of selections in advanced generations proceeds to the right of the serial number in the identification; the treatment index numbering proceeds to the left of the serial number so that the last treatment follows directly the designation of the year

FIG. 4.—Hudson Manchu soybean plants grown in root temperature control apparatus. These temperatures were, from left to right, 7°, 17°, 27°, and 37° C.

tures. When grown at root temperatures from 12° to 22° C, the plants produced more top growth under the higher supplementary light intensity, whereas below 12° C, namely, 7° and 2° C, the plants produced slightly greater growth under the lower supplementary light intensity. The appearance of the plants in the jars gave somewhat clearer views of this difference than the dry weight data indicate. From these results, one might expect an additional increase in dry weight production and plant growth at 2° and 7° C and less damage from the lack of water absorption if the intensity of the photoperiod was further reduced. Such would not be true at any of the higher root temperatures since at 12° C or above, 120-foot candles of supplementary light increased dry weight production over the lower light intensity of 50-foot candles. With their root systems at 7° C or below, the plants suffered from inability to absorb sufficient water from the gravel culture to satisfy their requirements, as evidenced by wilting on clear days (Fig. 2). The study of mineral and water intake in experiments 4 and 5 will be presented in a separate paper.

ROOT TEMPERATURE AND ROOT GROWTH

The temperature of the root environment influenced dry weight production of roots to a somewhat lesser degree than was true of the tops. This is indicated in Table 2 by the "F" value of only 3.37 which is somewhat below the value necessary for significance. However, as shown in Table 2, root growth in a general way tended to show an increase with increasing root temperature from 2° to about 27° C.

TABLE 2.—*Influence of root temperature on dry weight production of soybean roots for five experiments with analysis of variance on data from experiments 2, 3, and 5.*

Root temperature, °C	Mean weight per plant (grams) for experiment				
	1	2	3	4	5
2	—	—	—	0.02	—
7	0.62	0.11	0.07	0.03	0.06
12	—	—	—	0.06	0.29
17	0.99	0.24	0.16	0.06	0.36
22	—	0.29	0.14	0.09	0.31
27	1.35	0.36	0.18	0.10	0.27
32	—	0.26	0.12	—	0.41
37	1.16	0.31	0.15	—	0.19

Analysis of Variance

Variation due to:	Degrees of freedom	Mean square	F
Runs	2	0.0326	
Treatments.............	5	0.0155	3.37
Error (runs × treatments)	10	0.0046	

It was also observed in these studies that the intensity of the light was the controlling factor in determining the magnitude of response of root development to each increment of root temperature.

ROOT TEMPERATURE AND TOP: ROOT RATIOS

The influence of root temperature on the ratio of tops and roots may be observed for each of the five experiments in Fig. 3, lower left. These data show a surprisingly close relationship between production of tops and roots over a wide range of root temperature during the first 30 to 45 days of plant growth. The top:root ratios fluctuated from about 5 in experiment 1 to about 13 in experiment 4. The ratios seem to be determined predominantly by the light intensity since the biggest difference in the aerial environment between experiment 1 with a top:root ratio about 5 and experiment 4 with a ratio about 13 was the intensity of the photoperiod. As a matter of fact, the uniform increase in top:root ratios from experiment 1 to experiment 4 is in inverse relationship to the intensity of the photoperiod. An examination of the dry weight data shows that this increasing top:root ratio with decreasing light intensity is caused by a larger proportional reduction in root growth than in top growth. The analysis of variance of the data shows a nonsignificant difference among top:root ratios due to temperature treatments.

ROOT TEMPERATURE AND PLANT HEIGHT

The height data from experiments 2, 4, and 5 are given graphically in Fig. 3, lower right. In general, the height of the plants increased with root temperatures from 2° to about 17° C, remained fairly uniform from 17° to about 27° C, and decreased at 37° C. It appears

in which that treatment occurs. Selfed seed from selected plants from the progeny 31–20 may be composited as 411–20 if desired; seed produced by sib-pollination could be composited as 421–20.

It is usually desirable to renumber whenever radical change occurs in the objectives of reselection or in the genetic make-up of plant material, or whenever the numbering becomes too complicated. In this way the smaller serial numbers soon become obsolete and in the course of a few years might be used over again at the discretion of the worker. However, it has been found quite easy to run the serial numbers of selections into four digits. If four figures are not objectionable, the serial numbers up to 9999 allow considerable leeway before they need be used again.

On renumbering, the source of the material and the previous breeding history of the selection are recorded with the new serial number. Only the last significant breeding procedure is indicated by a treatment index number with the new serial number.

The treatment index is considered the outstanding feature of the system. By using treatment index numbers, duplication in numbers can be avoided and the assignment of new numbers greatly reduced. The system has distinct advantages in keeping track of the changing genetic composition of cross-pollinated perennials where several different breeding technics are being used simultaneously. Plant materials with the same origin may carry the same serial number with different treatment index numbers. Comparisons of different breeding methods are readily made on that part of the material without the aid of source books. This reduction in new numbers to be associated with plant materials is a definite advantage in facilitating the breeding work.

Table 1 gives a description of the treatment index numbers which might be used in a forage inprovement program. A brief explanation of their application to a breeding program as diverse as may be encountered in this field of plant improvement appears to be in order. The forage crop breeder is usually concerned with several species, each of which may require entirely different methods of approach to improvement, In many cases in the beginning so little is known about the breeding behavior of the grass or legume that several methods may be profitably explored. This is particularly true of newly introduced species and of many of the native grasses with which very little intensive breeding work has been done.

The philosophies of improvement for such a group are as diverse as their breeding behavior. In such an unexplored field it may be assumed that the first steps in improvement of a new crop will come about from relatively simple selection and mass selection methods. A comprehensive plan was desired which would take into consideration the relative potential values of seed introductions or collections, as well as selections which might be made later in nurseries. With the proposed system one set of records of serial numbers may be used for several species, thus eliminating both duplication of books as well as numbers.

The plan devised for treatment index numbers, as given in Table 1, is an attempt to list in some order the several conditions surrounding

TABLE 1.—*Description of treatment index numbers for use in the identification of selections of cross-pollinated plants to designate the pollination conditions affecting the genetic composition of seed or the breeding procedure involved in improvement.*

Treatment index	Breeding procedure	Description of breeding procedure
1	Self-fertilization	Seed from a single plant or from selected related plants self-fertilized by isolation of the individual, by bagging or caging, or by other means.
2	Close breeding with selection, sibbing	Seed produced on a selected plant or plants allowed to cross-pollinate with related plants in isolation or by cross-bagging or caging.
3	Advance in generation	Seed from related plants grown together in isolation without further selection, thus producing an advanced generation without eliminating any old or introducing any new germ plasm; the seed increase of a strain, variety, or hybrid in isolation.
4	Controlled hybridization	Artificial manipulation to secure controlled hybrids between dissimilar plants of the same species or between plants of different species. This procedure usually involves emasculation to insure F_1 hybrids.
5	Natural crossing	Seed produced on a plant allowed to cross-pollinate with an unrelated plant in isolation or by cross-bagging; the seed from *one* clone, line, or single cross grown in a natural crossing block containing two or more such clones, lines, or single crosses planted together for the purpose of producing crossed seed.
6	Natural crossing, reciprocals composited	Seed composited from selected clones, lines, or crosses grown together for crossing in isolation; the seed composite of reciprocal crosses or from natural crossing blocks.
7	Polycross	Seed from a selected clone or inbred line grown in isolation with a large number of selected clones or strains for the purpose of evaluating general combining ability of the selection and securing new combinations of plant characters.
8	Topcross	Seed from a selected clone, line, or strain grown in isolation with one top-cross parent furnishing the bulk of the pollen for producing crossed seed. The top-crossed seed is used primarily for the purpose of evaluating the general combining ability of the selection.
9	Open pollination or mass selection	Seed from a single open-pollinated plant or from selected plants which may be growing with unselected or dissimilar plants of the same species; mass selection for ecotype in native stands; mass selection for type in fields, or within a progeny or strain.

TABLE 1.—*Concluded.*

Treatment index	Breeding procedure	Description of breeding procedure
0	Introduction of new material, miscellaneous	Seed or plants of unknown potentialities newly introduced into a breeding or testing program; the omission of a designation referring to the pollination conditions affecting the genetic composition of seed, hence, also, the propagation of plants other than by seed.
A, B, C, S, P, etc.		Special breeding methods or studies.

the making of seed selections, proceeding from the most definite to the least definite information regarding genetic composition. A set of 10 numbers and a few supplemental letters are sufficient to record these conditions using the index number 1 in the table for self-fertilization, and at the other extreme, the index number 0 for a seed collection about which little information is available. Although this arrangement of breeding procedures represents an attempt at logical order from the standpoint of the genetic composition of plant material, it appears desirable to discuss the breeding procedures as they might be encountered in the development of an improvement program with new material.

According to this plan, the introduction of new collections of seed or plant materials into a breeding and testing program would be designated by the treatment index number 0 (Table 1). Because of the implications assigned to this index number, it would never be applied to seed in a designation with other treatment index numbers. If considerable information was available about the seed lot or if it represented a type or strain of the species from a given locality, the mass selection designation number 9 might be applied. In preliminary testing of grasses representing ecotype selections or strains from farmers' fields, striking differences have been found which are sufficient to warrant the increase and use of these naturally occurring strains (1, 8, 9, 12). Such mass selection methods have contributed greatly to our agricultural history and should be given considerable emphasis in a program of breeding for a new crop. Then, too, the testing of these plant materials from such broad sources is also of prime importance in evaluating seed accessions from which superior breeding material is to come (10). It is frequently desirable to isolate space-plantings of individual plants from such seed lots for continued mass selection by rogueing out undesirable plants, or for the purpose of making individual plant selections to be more carefully tested for combining into new varieties or strains (6, 11).

In the selection of individual plants the broadest range of gene population is to be found in the seed from a self-sterile, cross-fertile plant subjected to open-pollination among a diversity of pollen sources. The index number 9 as applied to a single plant accordingly identifies only the maternal side of the inheritance of the resulting

progeny whether or not the mother plant is homozygous for the selected character. From the standpoint of the plant breeder all of the other breeding procedures deal with the control of the paternal side of the inheritance either to learn more about the breeding behavior of the mother plant, to fix desired characters, or to produce new combinations of desired characters.

Tests of the breeding behavior of a selection of a cross-pollinated biennial or perennial plant may be conducted in several ways. Its self-fertility or self-sterility may be investigated by obtaining self-fertilized or close-bred seed and its selfed, close-bred, and out-crossed progenies may be grown and compared (7). If its breeding behavior should be determined to be superior, the mother plant itself may be used in further breeding procedures without the necessity of using its progeny as would be the case with annuals.

The production of selfed seed (index No. 1) is recognized as a fundamental procedure in securing improvement with many crops. With cross-pollinated grasses it is frequently difficult to obtain selfed seed by bagging or caging of the plant (1, 5, 7, 8, 11). This may result from inherent self-sterility or from unfavorable environmental factors. Although easier to achieve with normally self-pollinated plants, it is by no means confined to this group as an improvement procedure. Inbreeding may be considered either an objective, as in the production of inbred lines for the purpose of recombination, or a technic used solely for the evaluation of the breeding behavior of plant material under test. The decision as to its use in the breeding program for a particular species is an important one, dependent of course on the nature of the plant and the objectives of the plant breeder.

In the breeding of normally cross-fertilized plants the determination of self-sterility is an important consideration (13). If a plant with chosen characters is self-sterile, it may be used to secure hybrids with other selections through "natural crossing" by wind or insects without the necessity of emasculation (2, 13, 14). On the other hand, a plant which proves to be self-fertile may be tested for its relative homozygosity for selected characters by growing its selfed progeny. Selection within a progeny of a self-fertile plant may disclose a self-sterile plant with the desired characters which may be used in hybridization by natural crossing methods. The increase in the proportion of relatively self-sterile plants in selfed lines as compared to open-pollinated lines has been demonstrated with alfalfa (14). The difficulties of obtaining advanced generations of selfed lines with many cross-pollinated grasses has also become generally recognized. Thus with the selection of self-sterile, cross-fertile plants produced by controlled or natural conditions, suitable hybrids between plant materials with desired characters may be secured without resorting to hand crossing methods.

The continued inbreeding of normally cross-fertilized species usually results in a loss of vegetative vigor (11, 13). Frequently this reduction in vigor is so drastic as to make the resulting inbreds of little value for recombination. If it is desired to retain certain plant characters free from change by outcrossing to other material, it may

be more advantageous to close-breed by the isolation of selected plants or by the transfer of pollen as in sib-pollination or back-crossing (index No. 2). The labelling of such closebred seed from individual plants would require the use of pedigree numbering attached to the previously used serial number, or the seed could be numbered more simply with a new serial number. With certain grasses, as well as with many other cross-fertilized crops, a much larger seed set can usually be obtained by close breeding than by selfing (13); the losses in vigor may be less detrimental, allowing a better chance for selection of desired characters for out-crossing.

It should not be overlooked that a progeny resulting from a planned hybridization must be close bred in the sense that it must be protected from further out-crossing if a true segregation is to be expected in the succeeding generations. The index number 3 is especially useful in a breeding program for indicating the advance in generation of any plant material which is allowed to segregate normally without selection or contamination from other material. This treatment index, designed primarily for application to inbred lines and to hybrid progenies, may be extended to include the seed increase of a strain or variety in isolation. The number has its greatest usefulness as prefixed to a formerly used serial number following the year designation of seed harvest in the identification.

Segregating generations of a cross may also be obtained by self-fertilization of a selected hybrid plant or plants (index No. 1) or by the close-breeding of a progeny with a selection of individuals (index No. 2). This is often a desirable practice with crosses made by natural crossing methods, since they are usually not entirely effective and the resulting progenies may include plants resulting from self- or sib-fertilization as well as hybridization.

A large number of unrelated selections having been made, they may be evaluated further by tests of combining ability (11, 13). Descriptions of two procedures are given under index numbers 7 and 8 in Table 1. The general combining ability of a plant may be determined by growing its clones with several other unrelated carefully selected plants to secure polycrossed seed (index No. 7). By comparing the resulting progenies or polycrosses (13) of the several selected individuals in the block, those showing the best combining ability with the mass of pollen may be selected. In numbering the polycrossed seed, the polycross block designation may be attached to the serial number as a suffix to record the plants in the block to which the selection might have been crossed if several such blocks are being used. For example, seed from the clone 30–20 grown in a polycross block designated as II in 1945 would carry the polycross identification, 57–20 II. A record of the plants in the block would automatically be recorded in the seed inventory of that year. The index number 7 might also be used to indicate a polycross obtained on an inbred line outcrossed to other selected lines. The polycrossed seed of an inbred line, such as 41–30, harvested in 1945 would be labelled 571–30 with the appropriate isolation block designation indicating the other lines with which it may have crossed. This

method differs from using clonal lines only in that sibbing might occur to a slightly greater amount than selfing.

The seed of a clone 30–20 grown in 1945 with a topcross parent furnishing the bulk of the pollen in an isolation block would be numbered 58–20; the seed produced by an inbred line 41–30 grown with a topcross parent would be numbered 581–30.

If it is desired to evaluate the specific combining ability of two individuals, their clones may be grown together in isolation or seed may be obtained by an exchange of pollen in bags or cages (index No. 5) (6). Seed from two plants in a natural crossing block would be harvested and numbered separately as reciprocal crosses. Seed produced in 1945 would be numbered with the female parent designation first and with the male parent designation as a suffix separated by an ×. Examples: 55–20×60 and 55–60×20. When the reciprocal progenies are grown for comparison with each other and with selfed or close-bred progenies in suitable tests, the extent of cross-pollination between them as well as their reciprocal combining ability may be determined. If the reciprocally crossed seed is composited, the index number 6 would supplant the index number 5 in the identification, thus 56–20×60. If a cross is made in which the probabilities of securing selfed seed are greatly reduced by the emasculation of the female parent, the treatment index number 4 would be used. A double cross may be numbered in the same manner as a single cross, if the contributing single crosses are renumbered. The possibilities of utilizing hybrid vigor in such crosses have been presented for alfalfa (13, 14).

The steps in the final evolution of a new strain or synthetic variety are provided in the combination of treatment index numbers which may be assigned as a result of the breeding procedures affecting selections and crosses. The index numbers 1, 2, 3, 7, 8, or 9 may be used preceding another index number in an identification to indicate the pollination conditions affecting an advanced generation, without the assignment of a new serial number. The index numbers 4 and 5 apply initially to crosses. The index number 6 supplants the number 5 to signify the hybridization of genetic material plus the combination of resulting seed. The index number 0 should be used for combinations of unrelated seed from diverse sources. Used in this sense it would be comparable to syn-0 as has been used in the improvement of alfalfa, and would be dropped out of later designations showing advances in generation.

Strains might be developed through selection within the progeny of a given cross grown in isolation (index No. 2) followed by the increase of the strain during later generations, or the cross might be carried into advanced generations without further selection (index No. 3). For example, the cross 55–20×60 advanced in generation in 1946 would have for its seed designation the number 635–20×60. If the reciprocally crossed seed of 20 and 60, grown in 1945, were composited, it would be numbered 56–20×60 or the hybrid seed would be given a new serial number (such as 90) with the treatment index number 6 for identification, as 56–90. The significance of the new serial number and the relative amounts of seed composited

would be recorded in the accession books. It could be increased in the next generation in 1946 as 636–90.

A strain might be developed similarly from a crossing block (designated as III) in which a proven selection, 20, was out-crossed to several desired pollen parents. The seed selection designation in 1945 would read 55–20 III and upon isolation in 1946 it might produce seed designated as 635–20 III. If desired, the crossing block itself may be given a serial number (such as 100) denoting all of the included plant materials. The seed from a given selection would then be numbered in the same manner as a single cross, such as 55–20×100. Seed composited from such a natural crossing block limited to proven individuals with suitable combining ability would carry the number 6 with the new serial number denoting the crossing block and appropriate recorded description as 56–100. Besides the information on the last breeding procedure carried by the index number, the newly applied serial number and the crossing block designation, if used, would furnish all the other necessary information and differentiate the strain so formed from a single or double cross. The use of treatment index number 6 would be comparable to the use of syn-1 (13). A combination of index numbers 3 and 6 would be comparable to syn-2, etc. After the strain becomes established to the satisfaction of the plant breeder the need for any treatment designation other than one to signify the isolation required for the maintenance of purity (index No. 3) will have become unnecessary.

The foregoing discussion of treatment index numbers is intended to set forth how these might be used in an extensive breeding program with cross-pollinated perennials. Since the outstanding feature of the numbering system is the connotation of the treatment index number in the identification of a selection, this part of the plan might be adopted and revised for various purposes. It is doubtful if a completely uniform system should be adopted for all workers. For example, different treatment index numbers have been used by both the alfalfa and grass breeding projects at the Nebraska Station during the development of the numbering system and they have been assigned variously to breeding procedures (14). However, the treatment index numbers here presented appear to answer the broader needs of both these programs at the present time. It has been thought best to leave to the discretion of the individual the application of symbols to particular detailed procedures with which he alone might be concerned. Reserving the ten numerals for the most used procedures, the capital letters, A, B, C, etc., might be used for special breeding methods or studies. In this connection the letters A and S are suggested for detailed methods of obtaining self-fertilization, the letter B for a special back-crossing technic, D for diallel crossing, etc. These index letters could be interspersed in the table following the most nearly related treatment index number which they would supplant.

A word of caution should be added. It can be seen from these examples that any numbering system can become complex. At this point in a program it is always best to apply a new serial number and to record its full significance. It is not necessary to have treat-

ment index numbers or letters to transmit information which can readily be recorded in the accession record. It should also be kept constantly in mind that a definite breeding procedure for each crop should be established and that the numbering system be used as a means to that end. Accordingly, the ramifications of the system need not be exploited. Since the numbering system is a reflection of the plant breeder's objectives, these should be kept as simple as the complex breeding behavior of his plants will permit.

SYSTEM FOR TAKING NOTES

A subject closely related to a numbering system for a plant breeding project is a method of recording comparative notes whether it be for individual plant, row, or plot studies. With the development of the cooperative nurseries in the Alfalfa Improvement Conference there was a demand for uniform note taking so that results from various stations could be easily interpreted, averaged, and summarized. It was obvious that such notes as "slight," "medium," or "strong" could not be averaged with "+," "±," and "–." The Alfalfa Conference, therefore, decided to use numerical records in all note taking. Although a numerical method of recording notes was not new, a systematized method of application was not being used. As a result of a number of requests, H. L. Westover and the junior author prepared a group of headings and suggested numerical classes for use in the uniform nurseries. These have proved quite useful and a description of them as now used in both alfalfa and grass uniform nurseries is here presented for those who may be interested.

The two chief principles in this system of note taking are first, that notes are recorded numerically using a scale from 0 to 10, and second, that where possible the lowest figure represents the most desirable expression of the character. The latter principle has been very useful and for this reason will be discussed in some detail. In disease observations, it might be taken for granted that absence of disease is recorded as 0, little as 1, medium as 5, and severe as 9, but in notes on vigor of growth, for example, strong, vigorous growth might be recorded as 8 or 9 as readily as 1 or 2. If, however, the second principle is followed, *viz.*, the better the expression of the character the lower the figure, strong, vigorous growth (or absence of disease) would always be recorded as 1, medium vigor of growth as 5, and very weak growth as 9. The verbal expression of these numerical notes regarding a plant character could accordingly be expressed thus: 1 = excellent, 3 = good, 5 = medium, 7 = fair, 9 = poor, arranged about the average or median of 5, or 50%.

In estimating seed production, observers may be accustomed to giving the plants with the most seed the highest number and it might seem awkward to give the highest seed producers the lowest number. But, if the observer thinks of classifying the plants of first choice, second, third, and so on, it becomes natural to place the best seeders in the No. 1 class and the very poorest in the 8th or 9th. In fact in some cases it seems to "streamline" the note taking to think of the

best plants for each character as the No. 1 in the group or in other words, as being at the head of the class.

There are a few instances where it is difficult to decide which is the better expression of a character, and therefore, which is 1 or 9. For example, prostrate habit of growth in alfalfa may be desirable for certain purposes, in other cases an intermediate type, and in others a very upright type might be most desirable. Ordinarily the intermediate to upright type might be preferred but it would be recorded as 4 or 5, not 1 which is reserved for the most upright plants. Such instances, however, are comparatively rare.

Several other reasons why it has been found desirable to adhere to the principles of this system are that when a recorder inadvertently omits a footnote reference to the scale used in notetaking, he, or more particularly someone else who has to summarize the data, is not at a loss to understand the scale. It is very desirable, however, to have a clear, written description of the meaning of the numerical notes which are recorded. The application of this method of note taking also makes it possible to average several different characteristics of strains, in which case the strain having the lowest average has the more superior characteristics. In evaluating selections it also has been found helpful to take a single note representing the observer's estimate of the strain as a whole. This is called a "desirability" note, taken on the same scale as the other notes. These notes make it possible to eliminate selections lower than a selected standard. On the other hand, selections of outstanding merit for certain characters may be retained for special breeding purposes even though their average ratings may be low.

In the case of actual yield data and percentage survival, the higher the figures the better the strain in contrast to the notes discussed above. Such data, however, are usually treated or summarized separately from the observational data and in any case need not be confused with the conditions imposed by the system. Stands, winter injury, and bloom may preferably be recorded in per cent, but they may also be taken on the 1 to 9 scale of observational notes.

It is not necessary and often not desirable to use the full scale for any one particular set of notes. If, for example, notes are being taken on a disease which is not severe in any of the plants under observation, only the lower portion of the scale, say from 1 to 5, would be used. It is also obvious that the intermediate readings, 2, 4, 6, and 8, may be used. In special cases or in averages of several determinations, even the smaller divisions such as 2.5, 3.5, etc. assume significance.

This method of note taking is applicable to a wide range of different types of observations including those on plant characteristics, incidence of diseases, insect injury, and crop production notes.

SUMMARY

A system of numbering plant and seed material for use in the improvement of cross-pollinated forage grasses and legumes is

presented. As a basic system it is broadly applicable and flexible for use in the breeding of any crop. The essential features of the system include the designation of the year of seed production or plant selection and a treatment index number giving the breeding procedure or the conditions under which seed is produced. These designations are prefixed to the serial number of a selection. The year of selection appears first in the identification, and, for brevity, is the last figure of the applicable calendar year. It is followed by number or letter as a treatment index. These are separated from the serial number by a dash. Selections are serially numbered over a period of years with descriptions of the plant material recorded in accession books.

The proposed system of numbering is advantageous to a breeding program in the ready recognition of plant and seed material and seed materials with a minimum of numbers and in keeping track of changes in genetic composition during the process of improvement. It may also aid in the selection of definite breeding procedures for a given kind of plant. A set of treatment index numbers with descriptions of breeding procedures to which they refer and examples of their use are presented to show their application in a plant improvement program.

A plan is also described for the numerical recording of comparative notes on plant materials. In this system of note taking, the lowest figure in a scale of 1 to 9 represents the most desirable expression of the character. The application and advantages of such a system are discussed.

LITERATURE CITED

1. ANDERSON, KLING, and ALDOUS, A. E. Improvement of *Andropogon scoparius* Michx. by breeding and selection. Jour. Amer. Soc. Agron., 30:862–896. 1938.
2. ATWOOD, SANFORD S. Natural crossing of white clover by bees. Jour. Amer. Soc. Agron., 35:862–870. 1943.
3. BABCOCK, E. B., and CLAUSEN, R. E. Genetics in Relation to Agriculture. New York: McGraw-Hill Book Co., Inc. Rev. Ed. 1927. (Chapter 37.)
4. HAYES, H. K., and IMMER, F. R. Methods of Plant Breeding. New York: McGraw-Hill Book Co., Inc. 1942. (Chapter 5.)
5. HAYES H. K., and SCHMID, A. R. Selection in self-pollinated lines of *Bromus inermis* Leys., *Festuca elatior* L., and *Dactylis glomerata* L. Jour. Amer. Soc. Agron., 35:934–943. 1943.
6. JENKIN, T. J. The method and technique of selection, breeding, and strain-building in grasses. Imp. Bur. Plant Gen., Herbage Plants Bul. 3:5–34. 1931.
7. KIRK, L. E. The progeny test and methods of breeding appropriate to certain species of crop plants. Amer. Nat., 67:515–531. 1933.
8. LAW, ALVIN G., and ANDERSON, KLING, L. The effect of selection and inbreeding on the growth of big bluestem, *Andropogon furcatus* Muhl. Jour. Amer. Soc. Agron., 32:931–943. 1940.
9. NEWELL, L. C., and KEIM, F. D. Field performance of bromegrass strains from different regional seed sources. Jour. Amer. Soc. Agron., 35:420–434. 1943.
10. STAPLEDON, R. G. Methods as applied to cocksfoot grass, *Dactylis glomerata* L., and remarks as to technique in general. Imp. Bur. Plant Gen., Herbage Plants Bul. 3. 1931.
11. STEVENSON, T. M. Improvement of cross-fertilized crops—strain-building. Sci. Agr., 19:535–541. 1939.

12. TURESSON, G. The genotypical response of the plant species to the habitat. Hereditas, 3:211–350. 1922.
13. TYSDAL, H. M., and KIESSELBACH, T. A. Alfalfa breeding. Nebr. Agr. Exp. Sta. Res. Bul. 124. 1942.
14. ———, ———. Hybrid alfalfa. Jour. Amer. Soc. Agron., 36:649–667. 1944.

INVESTIGATIONS WITH THE CASTOR BEAN PLANT: I. ADAPTATION AND VARIETY TESTS[1]

W. E. Domingo and D. M. Crooks[2]

WORLD War II increased the need for drying and nondrying oils at a time when most of the American importations of these oils were either curtailed or seriously threatened by military activities. Castor oil, which is extracted from seed of the castor bean plant, *Ricinus communis* L., and which had become increasingly popular for industrial uses in pre-war years, played an important role in meeting these requirements. New processes referred to as dehydration convert it into a drying oil which is an acceptable substitute for certain oils, is a valuable constituent in some coatings, and is preferable to other oils for particular finishes. The normal extracted oil possesses qualities which make it desirable for hydraulic mechanisms, and it is used in the manufacture of soap, linoleum and oil cloth, printing ink, leather, and textiles.

Commercial production of castor beans in this country in the years just prior to the war was negligible. Importations of beans, largely from Brazil, exceeded 164 million pounds in 1936 and more than twice that amount in 1941. As a matter of preparation for possible commercial production in this country, intensive work was initiated in 1941[3] to (a) determine the area in this country best suited to the production of castor beans; (b) collect, evaluate, and increase seed supplies of the available "strains"; and (c) determine the most effective cultural methods and what production problems might be encountered. The work was conducted by the Bureau of Plant Industry, Soils, and Agricultural Engineering cooperating with many state agricultural experiment stations and individuals. It is not possible to list here all of the cooperators; however, the mimeographed reports (9, 10, 11)[4] summarizing the work annually from 1941 to 1943 give their names and the nature of their participation. This is the first of a series of three papers compiling those results according to phases of work.

METHODS AND RESULTS

ADAPTATION

Sketchy indications of adaptation of this species to conditions in the United States are furnished by very inadequate records of previous production and field tests. Mention has been made of cultivation in Kentucky and New York in 1803. Production in the early 19th century centered in Oklahoma, Missouri, Kansas, and Illinois. The 1850 census indicated the existence of 23 extraction mills from Illinois to Pennsylvania in the north to Arkansas and Alabama in

[1]Contribution from the Division of Tobacco, Medicinal and Special Crops, Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture, Beltsville, Md. Received for publication April 10, 1945.

[2]Agronomist and Principal Horticulturist in Charge, respectively.

[3]From 1938 to 1940 a few state agricultural experiment stations had conducted variety tests with miscellaneous strains and seed supplied by the U. S. Dept. of Agriculture.

[4]Numbers in parenthesis refer to "Literature Cited", p. 761.

the south; however, 70% of the oil was extracted in mills in Missouri. Following the Civil War, Kansas became the chief production area with an estimated crop of 766,000 bushels in 1879. During the next two decades the center of production shifted from Kansas to Oklahoma and domestic production decreased rapidly to less than 100,000 bushels annually after 1892. Production has been negligible since about 1900 except in 1918 when the heavy demands for aircraft lubrication resulted in a production program under the direction of the army. A considerable acreage was established in North and South Carolina, Florida, Georgia, Alabama, Mississippi, Louisiana, Arkansas, Texas, and California; however, because of disease, poorly adapted varieties, and inexperience with the crop, only about 250,000 bushels were produced.

Specific adaptation information was obtained from 1941 to 1943 by planting experimental plots[5] in many states for observations on yield, incidence of disease, insect damage, and reaction to different soil types, growing seasons, and the supply and distribution of moisture. The states in which these plantings were made were Alabama, Arizona, Arkansas, California, Florida, Georgia, Illinois, Indiana, Kansas, Kentucky, Louisiana, Maryland, Minnesota, Missouri, Nebraska, New Mexico, North Carolina, Ohio, Oklahoma, South Carolina, Tennessee, and Texas. This area is roughly the southern half of the United States exclusive of Nevada, Utah, and Colorado, and includes a great variety of growing conditions.

The experimental plantings were conducted at 73 locations in 1941, 60 locations in 1942, and 34 locations in 1943. In addition to furnishing adaptation information, the majority of the 1941 and 1942 tests compared varieties, and the remainder compared either dates of planting, rates of planting, or fertilizers. In 1943 replicated tests, largely of the split-plot design comparing both varieties and cultural methods, were conducted in the area which seemed at that time to be best suited to castor bean production. Tests outside of that area in 1943 consisted of small unreplicated plots of the main varieties for miscellaneous observations.

In Table 1 are shown the locations where tests were conducted as well as the average yields in pounds of shelled beans per acre for each test on which yield data were obtained. Many of the locations had more than one type of test each year and in those cases the tabular datum for the location is a mean of the average yields of the tests. While yield is a criterion of general adaptation, the conclusions concerning adaptation which may be drawn from these yield data are limited by several facts such as (a) most of the tests compared both good and poor treatments, e.g., varieties, or date-of-planting, etc., and the yields of all treatments contributed to the average yield of the test; (b) in all 3 years many of the yields were low because of late planting which was due in 1942 and 1943 to wet springs and in 1941 to a wet spring in certain localities and the late date that the

[5]Additional information on adaptation was collected in these same years from commercial acreages in Indiana, Illinois, Kentucky, Tennessee, Missouri, Kansas, Oklahoma, and Texas which were grown for seed increase of certain varieties under federal contract.

TABLE 1.—*Yields in pounds of hulled (threshed) beans per acre for tests where yield data were obtained.**

State	Town	Pounds of threshed beans per acre		
		1941	1942	1943
Alabama	Auburn	452	967	227
	Belle Mina	—	1,067	990
	Headland	—	851	1,148
	Montgomery	488	—	—
	Tuskegee	—	452	304
Arizona	Mesa	1,757	2,134	—
	Tuscon	1,769	869	—
Arkansas	Batesville	—	488	293
	Fayetteville	—	461	†
	Hope	—	813	†
	Roseland	814	—	—
	Stuttgart	—	873	591
California	Bard	902	1,721	—
Florida	Brooksville	91	41	—
	Gainesville	168	355	—
	Leesburg	118	684	—
	Quincy	177	0	—
Georgia	Blairsville	—	1,258	—
	Cairo	75	—	—
	Experiment	—	856	—
	Tifton	262	—	—
	Ways	143	—	—
Illinois	Alhambra	872	—	—
	Brownstown	691	442	—
	Carbondale	559	—	—
	Elizabethtown	729	—	—
	Equality	744	—	—
	Muscoutah	799	—	—
	Robbs	608	691	386
	Sparta	440	—	—
	Urbana	1,554	1,005	1,260
Indiana	Bedford	632	1,126	—
	LaFayette	1,639	906	—
	Merom	603	—	—
Kansas	Altamont	300	—	—
	Hays	—	891	—
	Kingman	467	—	—
	Manhattan	—	1,010	1,050
	Maple Hill	1,240	—	—
	Mortonville	—	561	—
	Parsons	425	—	—
	Thayer	—	892	—
	Wichita	—	909	678
Kentucky	Lexington	1,445	1,550	1,194
	Princeton	1,038	1,108	981
Louisiana	St. Joseph	—	1,047	—
Maryland	Beltsville	985	1,420	1,329
Minnesota	St. Paul	—	0	0
	Waseca	—	0	0
Mississippi	Hattiesburg	345	—	—
	Poplarville	326	—	—
	Raymond	624	1,623	872

TABLE 1.—*Concluded.*

State	Town	Pounds of threshed beans per acre		
		1941	1942	1943
Missouri....	Columbia	734	1,079	—
	Deepwater	534	—	—
	Jasper	626	—	—
	Mexico	284	—	—
	Paris	875	—	—
	Sikeston	766	—	—
	Springfield	513	—	—
Nebraska....	Auburn	—	1,521	—
	Falls City	—	—	384
	Fremont	—	1,199	—
	Lincoln	—	953	988
New Mexico....	State College	1,626	1,818	2,053
North Carolina....	Statesville	—	1,077	†
	Rocky Mount	—	774	—
Ohio....	Columbus	—	764	—
Oklahoma....	Arapaho	183	—	—
	Ardmore	691	1,068	—
	Cherokee	615	—	—
	Chickasha	655	—	—
	Durant	416	—	—
	Greenfield	667	—	—
	Lawton	597	819	—
	Okemah	752	—	—
	Perkins	731	—	—
	Stillwater	652	774	360
	Tipton	1,557	—	—
	Watonga	—	770	—
	Woodward	927	—	465
South Carolina....	Columbia	—	576	939
Tennessee....	Clarksville	941	1,298	—
	Columbia	2,027	1,894	—
	Jackson	1,361	1,555	—
	Knoxville	924	978	809
Texas....	Angleton	178	461	—
	Beaumont	46	—	—
	Beeville	—	—	281
	Chillicothe	1,012	872	885
	College Station	259	—	—
	Denton	580	536	1,100
	Deport	246	—	—
	Greenville	571	312	—
	Iowa Park	454	1,212	520
	Lubbock	737	547	531
	Robstown	493	—	—
	Scottsville	317	—	—
	Temple	377	381	88
	Tyler	109	60	†
	Weslaco	631	1,336	†

*Wherever more than one type of test was conducted at one location in any one year, the datum presented is the mean of the average yields for those tests.
†Yield data not taken.

program was initiated; (c) much of the area had an unusually early frost in the fall of 1942; (d) most of the area, especially parts of Kansas and Oklahoma, had an unusually droughty summer in 1943; (e) certain tests were located on soil which proved to be unsuited

to the crop; and (f) some of the yields are from small unreplicated plots. The data, however, furnish a basis for consideration of specific factors governing adaptation which are discussed separately in the following sections. Attention will be given first to those factors which determine the boundaries of the major area of adaptation, which are disease, length of growing season, and rainfall, and then to factors of local adaptation which is largely a question of soils.

Diseases and insects.—Several diseases have been observed on the castor bean plant in the United States, but at present only one appears to be a limiting factor in determining areas of adaptation. This disease, gray mold, *Sclerotinia ricini* Godfrey, was first reported by Stevens (6) in 1918. Godfrey (2, 3) wrote further of the disease, describing the causal organism and recommending control measures. The damage is largely confined to the inflorescences which are attacked in all stages of development during wet periods. The gray fungal mass usually envelops and completely destroys the raceme. Godfrey (3) found the disease in Mississippi, Louisiana, Texas, and throughout Florida, and reported losses of 10 to 100% in affected districts. In the current studies the disease was serious in three southern states. In 1941 it occurred in Florida and southern Georgia; in 1942 it completely destroyed the inflorescences at Quincy, Fla., and greatly reduced the yield at Brooksville, Fla.; and in 1943 it attacked all inflorescences at Angleton, Tex. Thus it has been found in Georgia and four of the five Gulf Coastal states. Since, as reported by Godfrey, the disease is quite specific as to host plant, it is presumed that continuous planting in those regions would result in increasing incidence of the disease. The only known effective control measure is the planting of mold-free seed in areas where climatic conditions are not favorable to the disease. This eliminates a sizeable area of the Gulf Coastal section from the region of best adaptation of this species. This area includes all of Florida, most of Alabama, Georgia, Mississippi, Louisiana, and the coastal region of east Texas having a summer precipitation of more than about 20 inches.

Alternaria ricini (Yoshii) Hansford, which was first thought to be only saprophytic on castor beans, has been shown by Yoshii (12) and Stevenson (7) to be parasitic. This fungus has been found on castor beans throughout the area of the tests, although less frequently in the areas with low rainfall and infrequent periods of high humidity. It becomes established during humid weather on the capsules at any stage of their development, but most frequently either during the very early stage or after the capsules reach their full size. The extent to which this species causes losses has not been definitely established. It has been known to destroy young inflorescences completely, yet it probably causes little damage to beans which are relatively mature before the fungus becomes established. The organism appears to be widespread (7) and the extent of damage depends upon favorable conditions for fungus growth.

At Angleton, Iowa Park, Greenville, and Temple, Texas, plants were observed to be susceptible to attack by the cotton root rot fungus *Phymatotrichum omnivorum* (Shear) Duggar. This is in general

agreement with Taubenhaus and Ezekiel (8) who classify castor beans and cotton as "highly susceptible" (30 to 80% of the plants exposed die during the year), and soybeans as "extremely susceptible" (80 to 100% of the plants exposed die). However, at Iowa Park, less than 25% of the castor bean plants were affected, while on adjacent plots all of the soybean plants and roughly 50% of the cotton plants were noticeably affected.

Leaf spot, which presumably was due to a species of either *Cercospora* or *Alternaria*, was observed to cause abscission of the older leaves in several scattered tests. A wilt, possibly caused by a *Fusarium* species, destroyed some plants in the Leesburg, Fla., test in 1942.

A green stinkbug, *Pentatomidae*, was found to be abundant on the racemes in the blackland belt of Texas and at points in Florida. In some localities with a high stinkbug population the yields of beans were very low; however, it is doubtful that this insect caused serious direct loss by its feeding, but its mechanical damage to the capsule possibly facilitated the entrance and establishment of diseases such as gray mold and *Alternaria*.

Nematodes were observed to cause minor damage to this species in Florida, South Carolina, and Texas. Leaf hoppers, leaf miners, caterpillars, grasshoppers and Japanese beetles were occasionally noted to feed on the foliage, but their damage is not believed to be great.

Growing season.—With the southern boundary of adaptation determined by the gray mold, the question is raised as to how far north this species can be grown successfully. The present varieties continue to produce new inflorescences throughout the summer. This results in each plant having, at any time in late summer, racemes in all stages of development from unfertilized ovaries to mature capsules. Raceme development and maturity are stopped by the first freeze in the fall. Therefore, while the greater percentage of the seed is produced early in the season, the yield is limited by the length of the growing season. Yields have been consistently good at Urbana, Ill., which has an average growing season of 180 days. A good yield of seed was produced at Fremont, Neb., in a season shorter than its average of 161 days, yet seed failed to mature on the three common varieties at two points in Minnesota in 1942 and 1943 with growing seasons only a little shorter than that at Fremont. The area of adaptation for the three common varieties appears to be limited to those regions having growing seasons of approximately 180 days or more. Roughly this would include the southeastern half of Kansas, all of Missouri, the southern third of Illinois, southern Indiana, the southern tip of Ohio, and points south. In this regard, however, it is important to note that current breeding programs with this species are producing varieties which are quite early and will permit a revision northward of the boundary of adaptation.

Moisture.—Moisture is important in determining adaptation in that it affects germination, growth, and disease incidence. Mention has been made of the occurrence of gray mold in wet periods which are common in regions of high summer rainfall. This fact has eliminated most of the Gulf Coastal region and Georgia from the area of

adaptation. Coastal areas of North and South Carolina would apparently be eliminated for the same reason.

The castor bean could hardly be classed as especially drought resistant. It is true that its habit of continually producing new inflorescences safeguards it against total or even extensive damage by a few days of hot winds. However, prolonged periods of drought in midsummer cause defoliation from which the plant does not recover soon enough to mature seed.

With the southern and northern boundaries of adaptation determined by gray mold and growing season, respectively, moisture determines the general western boundary. Observations in Kansas, Oklahoma, and Texas indicate that between 15 and 20 inches of rainfall from April to September are essential to satisfactory yields. This would include in the area of adaptation practically all of that part of Kansas with satisfactory growing season and all of Oklahoma except the pan-handle. The south central and eastern parts of the Texas pan-handle and roughly the eastern one third of Texas are satisfactory as far as moisture is concerned, but gray mold and other factors eliminate much of the southern part of the latter section. A region within a radius of about 50 miles of Corpus Christi, Tex., also seemed to be well adapted except where tropical storms were severe. Excellent yields are obtained in irrigated valleys of New Mexico, Arizona, southern California, and southern Texas, but at present this species cannot compete with higher-value crops on most of the irrigated land in those areas.

This western boundary of adaptation is highly irregular, however, because of the variations in effect of low rainfall on soils of different textures occurring in that region.

Soils.—Within this outer general boundary of adaptation exist areas of greatly diverse suitability for the species. Most of these differences are due to soils or soil and rainfall relationships. This problem was studied in detail by field surveys of the soil and the crop performance on experimental plantings and seed increase fields. The detailed report[6] classifies all of the known soil types and phases within this region as to their suitability for castor beans. Further, it itemizes and discusses those characteristics which are necessary for a soil to be satisfactory for castor beans. Those desirable soil characteristics are as follows:

1. Exceptionally good surface and under drainage. This plant is adversely affected more than most field crops by inadequate drainage of surface or subsoil.

2. Sufficient subsoil permeability to insure the adequate movement of air and water and the growth of plant roots. This species has a wide and deep root system and a friable subsoil is essential for maximum root development. Also, soils with claypans or underlain with excessively sandy or gravelly material near the surface develop conditions of drought in the upper soil during dry periods.

---

[6]Unpublished report by E. W. Knoble, Associate Soil Scientist, Division of Soil Survey, Bureau of Plant Industry, Soils and Agricultural Engineering.

3. The capacity to warm up readily in the spring. Castor beans grown on soil which warms up readily in the spring have a better chance of maturing seed than those grown on heavy soil. This is especially true in the northern edge of the zone of adaptation. Conditions which make for rapid warming are texture and to a less extent organic matter. The loams, sandy loams, and loamy sands are better than clay loams, silty clays, and clays.

4. Adequate moisture storage to meet the requirements of the crop.

5. Freedom from conditions preventing the efficient and economical use of cultural implements.

6. Lack of steep slopes subject to destructive erosion. The crop offers poor protection against runoff and erosion, and it apparently leaves the soil in a looser condition than do most field crops.

7. Freedom from adverse chemical conditions, such as harmful concentrations of soluble constituents, high acidity, and from other special conditions that favor infestations of detrimental organisms. Castor beans succeed on either calcareous or acid soil, providing the subsoil is permeable and good drainage conditions prevail. Generally, however, highly acid conditions of the fine-textured soils are associated with either poor surface or under drainage, or slow permeability of the subsoil.

It was observed that the best yields were obtained on well-drained permeable soils, whether they were on bottomland, terrace, or upland. In those cases where vegetative growth was very rank on bottom land, the yields were not greatly different from those on less-rank growth. Unlike most field crops, the castor bean succeeds on either fertile or relatively unfertile soils provided the physical conditions are favorable for growth. The place of fertilizers will be discussed in a later paper of this series.

Obviously there is no extensive area with only good castor bean soil, and likewise at least small areas of suitable soils can be found throughout the area of adaptation outlined above. It is important, however, to note those sections in which the majority of the land consists of soil types and phases which are well suited for castor beans. The larger general areas of this type include sections in western Missouri, much of northeast and south central Kansas, sizeable areas of western Oklahoma and the valley of the Red River between Texas and Oklahoma, parts of western and central Kentucky and Tennessee, much of the Mississippi and Illinois river valleys in Missouri and Illinois, and an area in west central Illinois.

VARIETY COMPARISONS

Very few recognized varieties of castor beans were available for comparison when the program was initiated late in the spring of 1941. Quantities of seed from many sources were quickly accumulated and assigned an identifying name. Most of these have obscure ancestry, although several of them are known to have come from dooryard plants which probably descended from the earlier commercial plantings in this country. The practice of harvesting seed over a period of years from plants with undehisced capsules has resulted in the

development of some relatively nondehiscent types, and the loss of beans by shattering is no longer a serious problem with certain selections.

In 1941, 44 types were planted at as many places as the amount of seed and the time for organization would permit. There was necessarily much lack of uniformity of design between tests, but they served to decrease materially the number of varieties to receive serious consideration for use in the seed-increase program and in further cultural and variety tests. Table 2 shows the 1941 to 1943 yields for those strains which were grown at 10 or more locations in 1941. The data are averages of the yields of each strain at all locations and are listed in order of decreasing 1941 values. The values for 29 additional varieties which were each grown in 1941 at fewer than 10 locations are not included in the table since they are not considered comparable to the values based on more locations.

TABLE 2.—*Mean yields in pounds of hulled beans per acre of castor bean strains at various numbers of locations in 3 years, listed in the order of decreasing 1941 yields.**

Variety	1941		1942		1943	
	No. of locations	Mean yield	No. of locations	Mean yield	No. of locations	Mean yield
Arlington	16	998	—	—	—	—
Conner	91	804	61	941	23	795
Doughty 11	39	781	61	829	18	699
U. S. 4	53	763	61	936	—	—
Kentucky 38	47	735	61	886	21	737
Kansas Common	24	693	60	908	—	—
U. S. 7	52	672	61	925	—	—
Kolp	12	620	—	—	—	—
San Benito	25	619	—	—	—	—
Flowering	12	579	—	—	—	—
Scott	11	370	—	—	—	—
Woburn 6	11	279	—	—	—	—
Woburn 4	12	193	—	—	—	—
Woburn 2	12	128	—	—	—	—
Woburn 3	12	59	—	—	—	—

*The values for 29 additional strains which were each grown in 1941 at fewer than 10 locations are not included since they are not considered comparable to the values based on more locations.

The screening of types was largely done according to yield, general plant type, and uniformity of type. Uniformity of type, especially seed size, is an important varietal characteristic in this species in that it affects planting and hulling operations. When planting is done with a corn drill or similar mechanism, lack of uniformity of seed size prevents uniform stands and also permits seed breakage which, with a seed so high in oil, causes the collection of dirt which results in further trouble. New castor bean hullers (1, 4, 5) were designed to operate very efficiently with seed of uniform size, but seed of variable size cannot be threshed without cracking the brittle seed coat of some seeds which permits rapid deterioration of the oil. Another

criterion for selection was plant type.[7] Harvesting costs are lowest in types with large racemes since no machines are available for field harvest and this operation is at present done by hand.

The reduction in number of strains for consideration from 44 in 1941 to 6 in 1942 was primarily on the basis of yield and uniformity of type. The six chosen had been among the top yielders in 1941, except for those few which produced high yields under irrigation. The further reduction to three varieties, namely, Conner, Doughty 11, and Kentucky 38, in 1943, was based primarily on purity and plant type. The available seed stocks of Conner, Doughty 11, and Kentucky 38 produced more uniform plantings than U. S. 4, U. S. 7, and Kansas Common. Conner and Doughty 11 had larger racemes than Kentucky 38, but the latter was retained because of its relative earliness, which is essential in much of the test region. Also, since the plant type of Kentucky 38 is different from that of Conner and Doughty 11, that variety was used to furnish information on the interaction between plant type and cultural methods in split-plot tests in 1943.

Sixty-one variety tests in 1942 and 23 in 1943 compared these varieties critically. The following generalized statements can be formulated from those data:

1. In 1942 the Conner variety yielded highest or within the 5% range of error of the highest in 69% of the tests in which it occurred, and those data for Doughty 11 and Kentucky 38 were 41% and 54%, respectively. The same information for 1943 is 48%, 31%, and 16%, respectively.

2. Both Conner and Doughty 11 averaged about 4.5 and 3.5 spikes per plant in 1942 and 1943, respectively. For Kentucky 38 these data were 7.2 in 1942 and 6 in 1943.

3. Conner, Doughty 11, and Kentucky 38 were about 75, 74, and 60 inches tall, respectively, in 1942 and 76, 76, and 62 inches in 1943.

4. In 1943 both Kentucky 38 and Doughty 11 had hulling percentages[8] of about 70 which was significantly greater than that of 66.7 for Conner. This characteristic is of course of less practical value than yield of hulled beans unless low hulling percentage is found to be due to a disease which prevents normal filling of the seed, in which case the difference noted might suggest differences between varieties in resistance.

5. Both Conner and Doughty 11 were observed to lodge and shatter less than Kentucky 38.

---

[7]A number of public and private concerns and individuals designed castor bean hullers of various types, including modified combine threshing units and modified peanut hullers, all of which had considerable limitations. The two types of hullers that proved most effective and were constructed for use in the seed increase program in the United States and for commercial hulling in other countries were designed principally by E. D. Gordon and I. F. Reed, Associate Agricultural Engineers, U.S.D.A. Tillage Laboratory, Auburn, Ala., and H. A. Arnold, Associate Agricultural Engineer, Tenn. Agr. Exp. Station, Knoxville, Tenn.

[8]Hulling percentage is the weight of hulled, mature, sound, beans divided by the weight of the beans in the hull in dry condition but free from the central stems of the spikes.

DISCUSSION

Many growers who produced seed under a government agreement from 1941 to 1943 were favorably impressed with castor beans as a crop for their area. These growers included operators of both large and small farms in Kentucky, Tennessee, Indiana, Illinois, Missouri, Kansas, Oklahoma, Arkansas, and Texas. However, until oil extractors are located near the area of production and varieties are developed which lend themselves to the more mechanized harvesting on large acreages, domestic beans probably cannot compete with imported oil or with imported beans which are processed near the port of entry.

The recent experimental work not only has been insurance against a crippling shortage in this war but also furnishes a reservoir of knowledge for any possible future production in time of either restricted or unrestricted importation. The plant material collected and now being used for further development of more adapted types may well become significant in developing a new crop for diversification of agriculture in years of surpluses.

Current breeding programs will undoubtedly produce varieties which will be superior to those now available. In addition to greater yield and complete shatter resistance there is need for larger racemes on varieties to be used for hand harvest. Also, there is need for types with small stems for combine harvest of larger acreages. Manufacturers of farm implements are determining what adjustments are necessary in their present combines to make them suitable for castor bean harvest. Present indications are that the combine should not hull the beans but rather strip the capsules from the racemes for later hulling by a more specialized machine, possibly in a central plant. The hulling operation has been mechanized by the development of at least two different hullers (1, 4, 5) which do the job efficiently on dry seeds of uniform type.

SUMMARY

1. Experimental plantings at 73 locations in 1941, 60 in 1942, and 34 in 1943, along with seed-increase fields in the same years, furnished information on adaptation of the castor bean plant to conditions in most of the southern half of the United States and points as far north as Minnesota. Most of the tests also compared treatments such as varieties, rates of planting, dates of planting, fertilizers, and other cultural methods.

2. The main region of adaptation is determined by at least three major factors, *viz.*, disease, length of growing season, and rainfall. Only one disease, gray mold, *Sclerotinia ricini* Godfrey, has been definitely found to be important in this respect. In most of the Gulf Coastal region this fungus, which is quite specific as to host, has frequently caused severe loss by destroying the inflorescence in all stages of development. The only effective control measure known is the planting of mold-free seed in areas where climatic conditions are not favorable to the disease. This eliminates a sizeable area of the Gulf Coastal region from the area of adaptation.

The length of growing season is an important factor since this plant continues to produce and ripen racemes until damaged by frost. Yields of the three common varieties, Conner, Doughty 11, and Kentucky 38, have, in general, been good in areas with growing seasons of at least 180 days, while production was hazardous in areas with shorter growing seasons. Current breeding programs, however, are producing earlier varieties which will permit extending production into areas with shorter seasons.

Observations in Kansas, Oklahoma, and Texas indicate that between 15 and 20 inches of rainfall during the months from April to September are essential to satisfactory yields. Excellent yields were obtained under irrigation in the lower Rio Grande Valley in Texas and in New Mexico, Arizona, and southern California, but at present this species cannot compete with high-value crops on much of the irrigated land of that area.

These three factors outline an area of adaptation for the present varieties which includes, roughly, the southeastern half of Kansas, Missouri, the southern third of Illinois, southern Indiana, the southern tip of Ohio, the western and central parts of Kentucky and Tennessee, Arkansas, all of Oklahoma, except the pan-handle, and the part of Texas north of Dallas and east of Lubbock and the part within a radius of about 50 miles of Corpus Christi.

Within the general area outlined above are soils of different suitability for castor beans. The three main characteristics of a soil satisfactory for this crop are (a) exceptionally good surface and under drainage, (b) sufficient subsoil permeability to insure the adequate movement of air and water and the growth of roots, and (c) the capacity to warm up readily in the spring. Some of the larger general sections in which at least half of the land is of soil types and phases suitable for castor beans are listed.

3. The number of strains tested at one or more locations each year was reduced from 44 in 1941 to 3 in 1943. The selection of types for consideration was based largely on yield, purity, and raceme size. Conner, Doughty 11, and Kentucky 38 were the varieties studied most critically. Conner was most often the top yielder. Kentucky 38 is a shorter and earlier variety, but it has smaller racemes and exhibited a tendency to lodge and shatter under certain conditions.

LITERATURE CITED

1. Arnold, H. A., and Sharp, M. A. The improved castor bean sheller. Tenn. Agr. Exp. Sta. Bul. 187. 1944.
2. Godfrey, G. H. *Sclerotinia ricini* n. sp. parasitic on the castor bean (*Ricinus communis*). Phytopathol., 9:565–567. 1919.
3. ———. Gray mold of castor bean. Jour. Agr. Res., 23:679–715. 1923.
4. Gordon, E. D. Castor bean hullers. Agr. Eng., 24:189. 1943.
5. Reed, I. F., and Brown, O. A. The U. S. D. A. castor bean hullers. Agr. Eng., 25:290. 1944.
6. Stevens, H. E. Gray mold of castor beans. Fla. Grower, 18(8):6. 1918.
7. Stevenson, E. C. *Alternaria ricini* (Yoshii) Hansford, the cause of a serious disease of the castor bean plant (*Ricinus communis* L.) in the United States. Phytopath., 35:249–256. 1945.
8. Taubenhaus, J. J., and Ezekiel, W. N. A rating of plants with response to their relative resistance or susceptibility to *Phymatotricum* root rot. Tex. Agr. Exp. Sta. Bul. 527. 1936.

9. U. S. Bur. of Plant Industry, Soils, and Agricultural Engineering, Division of Drug and Related Plants. Results of the cooperative regional castor bean tests, 1941. Mimeographed. D.R.P. 34. 1941.
10. ———. Results of the cooperative regional castor bean tests, 1942. Mimeographed. D.R.P. 35. 1942.
11. ———. Results of the cooperative regional castor bean tests, 1943. Mimeographed. D.R.P. 40. 1943.
12. Yoshii, Hazime. [A leaf spot or blight disease of *Ricinus communis* L. caused by *Macrosporium ricini* n. sp.] Bul. Sci. Fak. Terkult. Kjusu Imp. Univ., Fukuoka, Japan, 3:327–332. 1929. (Japanese with English summary.)

THE EFFECT OF FERTILIZER ON STAND AND YIELD OF KUDZU ON DEPLETED SOILS[1]

E. C. RICHARDSON[2]

EXTENSIVE plantings of kudzu have been made on depleted soils throughout the southeastern part of the United States. Some areas, particularly in the Piedmont and Limestone valleys where kudzu has been planted, are so severely eroded that native vegetation is almost nonexistent. On other areas with less severe erosion, native vegetation offers some protection against erosion, but it competes with the kudzu plants and delays coverage.

At the beginning of the soil conservation program in 1935 there was little information available on the fertilizer requirements of kudzu under conditions mentioned above; therefore, some experiments were conducted to determine the response of kudzu to applications of various fertilizers, including lime, phosphate, and potash on depleted soils. The results of some of these studies are reported herein.

EXPERIMENTAL

Areas were selected in 1937 on which the kudzu had been set in the spring of 1935 with very little soil preparation or cultivation, and without fertilizer. When possible, plots were laid out in duplicate.

Green-weight yields in all tests were obtained in September of each year by cutting one or more areas 10×10 feet in each plot. After yield records were obtained, the kudzu on the remainder of the area was harvested for hay.

STUDIES WITH APPLICATIONS OF PHOSPHORUS, POTASH, AND LIME

In the spring of 1937 several kudzu areas in the soil conservation demonstration project in the lower Piedmont area near Dadeville, Ala., were selected for preliminary fertilizer studies. The fertilizer treatments used on each of these areas were: (1) no fertilizer, (2) 800 pounds of approximately 8% basic slag, (3) 150 pounds of 43% triple superphosphate, (4) 300 pounds of triple superphosphate, and (5) 300 pounds of triple superphosphate plus 1 ton of dolomitic limestone per acre. These fertilizer treatments were used with and without cultivation. The data from these experiments are not reported, but they showed that kudzu responded to applications of phosphate. Cultivation was of value in removing competing vegetation in the early stage of growth.

In 1938 and 1939 the studies were enlarged to include three sources of phosphate, *viz.*, approximately 8% basic slag, 16% superphosphate, and 43% triple superphosphate. Phosphatic fertilizers were applied separately and in combinations with lime and potash. Rates of applications were 800 and 1,600 pounds of approximately 8% basic slag, 400 and 800 pounds of 16% superphosphate, and 150 and 300 pounds of 43% triple superphosphate per acre. All of the fertilizers were applied at the beginning of the experiment and none was added during the period of observation. Outline of fertilizer treatments and arrangement of plots are shown in Table 1. These experiments were conducted in the Piedmont and Limestone valleys and the Coastal Plains of Alabama. The results obtained are shown in Tables 2 to 5, inclusive.

[1]Contribution from the Soil Conservation Service, Research Division, Auburn, Alabama. This study was made in cooperation with the Alabama Agricultural Experiment Station, Auburn, Ala. Received for publication April 19, 1945.

[2]Project Supervisor. Acknowledgment is made to J. W. McClendon, Assistant in Agronomy, and Dr. G. W. Volk, Soil Chemist, of the Alabama Agricultural Experiment Station staff, for assistance with the chemical analysis and the interpretation of results; and also to Dr. Henry Hopp, Soil Conservationist, Washington, D. C., for the statistical analysis.

TABLE 1.—*Outline of fertilizer treatments and arrangement of plots for an individual replication.**

Sub-plot 1	Sub-plot 2	Sub-plot 3
O	O	O
L	L	L
K	K	K
KL	KL	KL
B	S	T
TL	BL	SL
SK	TK	BK
BKL	SKL	TKL
2T	2B	2S
2SL	2TL	2BL
2BK	2SK	2TK
2TKL	2BKL	2SKL

*Materials and amounts applied per acre are as follows: B = 800 pounds of approximately 8% basic slag, S = 400 pounds of 16% superphosphate; T = 150 pounds of 43% triple superphosphate; 2B = 1,600 pounds of approximately 8% basic slag; 2S = 800 pounds of 16% superphosphate; 2T = 300 pounds of 43% triple superphosphate; L = 2,000 pounds of lime; K = 100 pounds of muriate of potash per acre. The sub-plots were 22 × 57 feet and were systematically arranged as shown above. Treatments were replicated two to four times at each location. Fertilizer treatments were applied broadcast at the beginning of the experiment, and none was added during the period of observation.

RESULTS

Kudzu responded more to phosphate than to the other fertilizers applied in these tests (Tables 2 and 3). Phosphate was essential for the development of satisfactory stands and cover of kudzu on depleted soils. The analysis of variance shows that the three sources of phosphorus (basic slag, superphosphate, and triple superphosphate) when used at a rate to supply the same amount of phosphorus did

TABLE 2.—*Effect of the application of various sources of phosphate on kudzu in yields in pounds per acre greenweight.**

Fertilizer treatment†	Sources of phosphate			
	None	Basic slag	Superphosphate	Triple superphosphate
O	6,114	——	——	——
L	6,033	——	——	——
K	6,191	——	——	——
KL	7,925	——	——	——
P_1	——	11,018	10,175	9,443
P_1L	——	11,666	10,547	11,665
P_1K	——	11,179	12,020	11,861
P_1KL	——	12,243	12,039	11,831
P_2	——	12,585	12,096	11,844
P_2L	——	12,556	11,733	12,180
P_2K	——	12,534	12,239	12,340
P_2KL	——	12,247	12,762	12,618
Average	6,566	12,004	11,701	11,723

*Average of yields from Kernodle, Beeland, Poole, Maharg, and Woodruff areas.
†L = 1 ton of dolomitic limestone per acre; K = 100 pounds of muriate of potash 50% K_2O per acre; P_1 = 800 pounds of basic slag, 400 pounds of 16% superphosphate, or 150 pounds of 43% triple superphosphate per acre; P_2 = 1,600 pounds of basic slag, 800 pounds of 16% superphosphate, or 300 pounds of 43% triple superphosphate per acre.

not differ in their effects; therefore, results from the various sources are averaged in Table 3. Yields from the different areas varied, yet differences as a result of treatment are consistent and highly significant (Tables 3 and 4). The double phosphate application increased the yield significantly over the single application (Table 5).

TABLE 3.—*Kudzu yields by farms and treatments, pounds per acre greenweight.*

Fertilizer treatment*	J. A. Kernodle, Dadeville, Ala., 1938–41 4-year average Cecil soil	Beeland Farm, Greenville, Ala., 1939 and 1940 2-year average Akron soil	R. E. Poole, Greenville, Ala., 1939, 1941, and 1942, 3-year average Ruston soil	S. T. Maharg, Alexandria, Ala., 1940 and 1941, 2-year average Baxter soil	Woodruff area, Alexandria, Ala., 1939 and 1941, 2-year average Decatur soil
O	5,991	6,251	3,721	8,403	6,570
L	5,170	7,667	3,350	10,563	6,004
K	5,473	7,587	3,260	10,944	5,848
KL	7,069	9,039	4,846	11,798	9,442
P_1	9,252	11,079	8,592	12,052	12,966
P_1L	10,288	12,716	9,202	13,867	13,402
P_1K	10,359	13,939	9,384	15,645	13,086
P_1KL	10,597	15,221	9,616	16,934	12,142
P_2	10,688	15,282	9,384	16,026	13,957
P_2L	10,906	16,498	8,850	15,173	13,104
P_2K	11,345	16,128	9,692	14,829	12,941
P_2KL	11,542	16,179	10,008	14,683	13,304

*L = 1 ton of dolomitic limestone per acre; K = 100 pounds of muriate of potash 50% K_2O per acre; P_1 = 800 pounds of approximately 8% basic slag, 400 pounds of 16% superphosphate, or 150 pounds of 43% triple superphosphate per acre; P_2 = 1,600 pounds of approximately 8% basic slag, 800 pounds of 16% superphosphate, or 300 pounds of 43% triple superphosphate per acre. Yields from different sources of phosphate are combined in this table. Average of 13 kudzu crops on farms listed above.

Kernodle's farm is located in the lower Piedmont, 4 miles west of Camp Hill, Ala. Beeland's and Poole's farms are located in the lower Coastal Plain, 5 miles east of Greenville, Ala. Maharg and Woodruff farms are located in the Limestone valleys, 8 miles north of Anniston, Ala.

TABLE 4.—*Analysis of variance of kudzu data, tons per acre greenweight.*

Sources of variation	Degrees of freedom	Sum of squares	Mean square
Trials (farms and replications)	31	3,187.93	102.84**
Treatments	11	1,914.76	174.07**
Sources of phosphorus	2	3.64	1.82
Interaction of treatments and phosphorus sources	14	23.32	1.67
Error (inconsistency of results for different trials)	1,093	2,224.04	2.03
Total	1,151	7,353.69	

**Highly significant, 1% level.

There was some increase in yields as a result of applying lime and potash; however, the application of these materials did not consistently result in increased yields. When applied alone neither lime nor potash produced a significant increase in yield. When lime and potash were applied in combination but without phosphate, there

TABLE 5.—*Mean kudzu yields according to treatments, pounds per acre greenweight.*

Lime and potash	Rate of phosphorus		
	None	Single	Double
None	6,114	10,212	12,175
Lime	6,033	11,292	12,156
Potash	6,191	11,686	12,371
Lime and potash	7,925	12,038	12,543

Minimum difference required for significance, at 5% level 806 lbs.; at 1% level 1,063 lbs.

was an increase in yield. From Table 1, it may be observed that the potash-lime treatment always occurred adjacent to the single phosphate treatment. Kudzu runners originating from plants located in the areas treated with phosphate overran to some extent the potash-lime plots which accounts for a part of the increase obtained from the potash-lime treatment.

When potash and lime were applied with the single application of phosphorus, higher yields were obtained. This was not true when applied with the double rate of phosphorus (Table 5).

Parker and Tidmore[3] found that an application of lime to acid soils increased the phosphorus in the soil solution. Salter and Barnes[4] found that moderate applications of lime resulted in increased crop yields. Therefore, the application of a ton of lime with the single application of phosphate probably increased the amount of available phosphorus which resulted in increased kudzu yields. The double application of phosphorus was probably sufficient to meet the requirements of the kudzu without the application of lime under the conditions of these tests.

EFFECT OF DIFFERENT RATES OF BASIC SLAG AND CULTIVATION ON YIELD OF KUDZU

Kudzu was planted on an area of severely eroded Madison clay soil in 1935. The area was located on Ed. Hill's farm near Camp Hill, Ala. Rows were spaced approximately 12 feet apart with plants spaced in the drill so as to give 1,000 crowns per acre. In March 1939 basic slag was applied at the rate of 400, 800, and 1,600 pounds per acre. In this study, basic slag was applied with no cultivation, partial cultivation, and complete cultivation. Partial cultivation consisted of plowing a strip approximately 4 feet wide along each side of the kudzu row. Complete cultivation consisted of plowing the entire area except a narrow strip along the kudzu row.

In all cases the fertilizer was broadcast at the beginning of the experiment, and none was added during the period of observation. The results are shown in Table 6.

[3]PARKER, F. W., and TIDMORE, J. W. The influence of lime and phosphate fertilizer on the phosphorus content of the soil solution and of soil extract. Soil Sci., 21:425–441. 1925.

[4]SALTER, ROBERT M., and BARNES, E. E. The efficiency of soil and fertilizer phosphorus as affected by soil reaction. Ohio Agr. Exp. Sta. 1935.

TABLE 6.—*The effect of various rates of basic slug and cultural treatments on the greenweight yield of kudzu in pounds per acre.**

Cultural treatment	Yields from basic slag applications			
	None	400-lb. rate	800-lb. rate	1,600-lb. rate
No cultivation	1,744	2,652	10,079	14,388
Partial cultivation	2,725	3,670	11,990	16,641
Complete cultivation	1,744	3,125	11,336	14,679

*Three-year average yield, 1940–42, Ed. Hill area, Camp Hill, Ala. The soil was Madison clay located in the lower Piedmont. Partial cultivation consisted of a strip approximately 4 feet wide along each side of the kudzu row plowed deep. Complete cultivation consisted of plowing the entire area except a narrow area along the kudzu row.

The results show that the 400-pound rate of basic slag was inadequate for the maximum growth of kudzu. Yields from the 800-pound rate approached that of the 1,600-pound rate; however, the higher rate maintained the production longer than did the lower rate. Cultivation was of little value other than for the destruction of weeds.

EFFECT OF FERTILIZER APPLICATIONS ON PHOSPHORUS AND CALCIUM CONTENT OF KUDZU HAY

The hay from the J. A. Kernodle farm was used for these tests. The fertilizer was surface applied to the kudzu in the spring of 1938. In September 1938 when yield determinations were being made, kudzu samples were collected from each plot. Additional samples were collected in the fall of 1941, 4 years after the fertilizer was applied. Calcium and phosphorus determinations were made on the kudzu samples by staff members of the Alabama Agricultural Experiment Station. Lime applications increased the calcium content of kudzu hay only slightly, while phosphate applications definitely increased the phosphorus content (Table 7). Hay from kudzu fertilized with 1,600 pounds of slag per acre contained a higher percentage of phosphorus than that from kudzu fertilized with 800 pounds of slag per acre. The percentage of both calcium and phosphorus was higher in the 1941 samples than in those collected in 1938.

Both lime and phosphate fertilizer were surface applied in 1938, and sufficient time had elapsed for it to enter the surface of the soil where the kudzu could utilize the fertilizer by 1941. The accumulated mulch conserved moisture and doubtless aided the kudzu in surface feeding, particularly during rainy periods in summer. Also, the root system of the kudzu plant had increased in size and was feeding in a larger zone; therefore, it was possible for the plant to draw more calcium and phosphorus from the soil in 1941 than in 1938 even on untreated plots.

The total amount of phosphorus removed by kudzu from the soil in 1941 varied according to treatment. Kudzu which received no phosphate removed approximately 6.50 pounds of P_2O_5, or an equivalent of 40 pounds of 16% superphosphate. Kudzu which was fertilized with 1,600 pounds of slag per acre removed approxi-

TABLE 7.—*Percentage of calcium and phosphorus in kudzu hay as affected by various fertilizers.*

Fertilizer treatment*	Calcium, %		Phosphorus, %		Amount of P_2O_5 per acre removed from soil by kudzu in 1941, lbs.
	1938	1941	1938	1941	
O	1.53	1.63	0.080	0.150	6.85
L	1.60	1.62	0.075	0.141	6.35
K	1.29	1.74	0.075	0.134	6.21
KL	1.22	1.70	0.079	0.132	7.27
P_1	1.37	1.60	0.092	0.164	12.54
P_1L	1.40	1.61	0.104	0.175	15.48
P_1K	1.29	1.46	0.108	0.167	17.27
P_1KL	1.35	1.60	0.106	0.165	15.69
P_2	1.42	1.45	0.110	0.223	22.54
P_2L	1.37	1.65	0.107	0.223	23.37
P_2K	1.37	1.37	0.109	0.241	26.89
P_2KL	1.37	1.78	0.103	0.248	26.68

*L = 1 ton of dolomitic limestone per acre; K = 100 pounds of muriate of potash 50% K_2O per acre; P_1 = 800 pounds of approximately 8% basic slag, 400 pounds of 16% superphosphate, or 150 pounds of 43% triple superphosphate per acre P_2 = 1,600 pounds of basic slag, 800 pounds of 16% superphosphate, or 300 pounds of 43% triple superphosphate. Determinations were made by members of the Alabama Agricultural Experiment Station staff.

mately 24 pounds of P_2O_5, or an equivalent of 150 pounds of 16% superphosphate per acre in 1941. This increase was due to a higher percentage of phosphorus and also to a higher yield per acre.

OBSERVATION

On severely eroded land kudzu on the unfertilized plots made poor growth (Fig. 1). Many of the crowns formed were weak and poorly anchored due to unfavorable growing conditions. Alternate freezing and thawing followed by rain and erosion exposed many of the new crowns and a portion of the root system. As a result of this exposure, a large percentage of the new plants were winterkilled and new growth started from the parent plant each year. This process of growing out and dying back continued until the dead vines and leaves formed a surface mulch. The mulch conserved moisture by reducing run-off and evaporation and protected the new crowns against winter injury. Applications of phosphate stimulated the growth of kudzu and hastened the development of a complete stand (Fig. 2).

Where the degree of erosion was not severe, other vegetation competed with kudzu for moisture and held the vines off the ground. This prevented contact of kudzu vines with the soil, which restricted crown formation and delayed coverage until the vines from original crowns were sufficiently vigorous to smother the competing vegetation. Fertilizer applications without cultivation stimulated the kudzu, but it also stimulated the competing vegetation. Largely because of competition from weeds, one or two years often were required to develop a complete stand after phosphate was applied. After kudzu overcame the competing vegetation, development was usually rapid. Fertilization, together with sufficient cultivation to eradicate weeds resulted in rapid coverage.

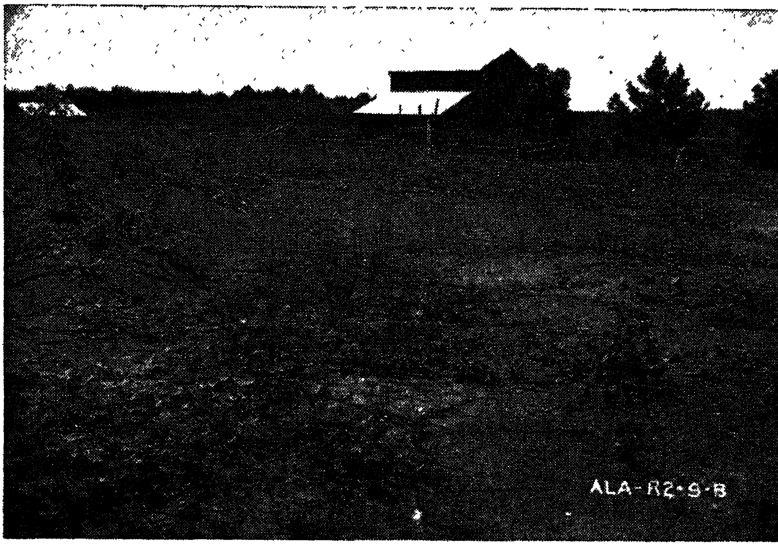

FIG. 1.—Kudzu planted on severely eroded Madison clay soil in 1935. No fertilizer was applied at planting time and none has been added since. Photograph was made August 25, 1942.

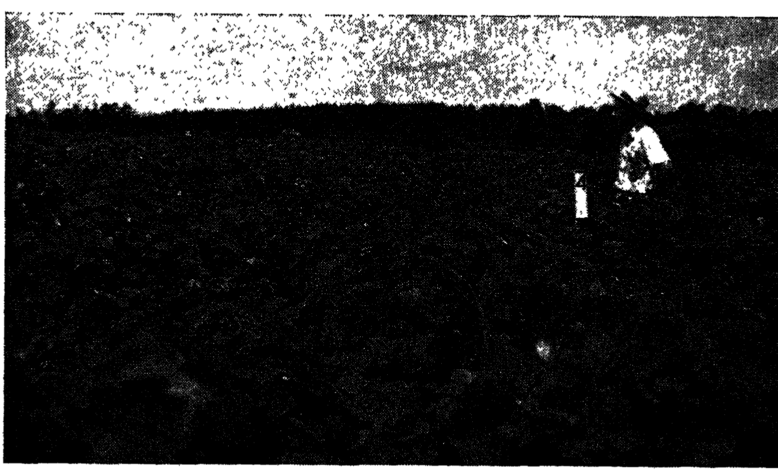

FIG. 2.—Kudzu planted on severely eroded Madison clay soil in 1935. No fertilizer was applied at planting time. In 1939 basic slag was broadcast at the rate of 1,600 pounds per acre. No fertilizer has been applied since. The average yield of hay in the years of 1940 to 1942, inclusive, was 2¼ tons per acre. Photograph was made August 25, 1942.

Before cutting or grazing kudzu every effort was made in all subsequent work to establish a thick stand of vigorous crowns. The application of adequate amounts of phosphate at planting time, together with clean cultivation for control of weeds, usually resulted in good

stands of crowns by the third year. When this stage of development was reached, a broadcast application of 400 to 800 pounds of superphosphate per acre, or its equivalent, developed the kudzu plants into full production by the end of the first or second growing season after the application. This application maintained satisfactory production over a period of 3 to 5 years.

CONCLUSIONS

The results obtained from experiments on the fertilization of kudzu lead to the following conclusions:

1. Addition of phosphate was essential for the establishment of satisfactory stands of kudzu on depleted soils. A rate of 400 to 800 pounds of superphosphate, or its equivalent, was needed for maximum yield.
2. Lime or potash, applied singly, without phosphate, had no significant effect on kudzu yield. However, when these two nutrients were applied together, or when they were used as a supplement to 400 pounds of superphosphate, increased yields were obtained.
3. The percentage of phosphorus in kudzu hay was increased by the addition of phosphate fertilizer. This effect was greater the third year after fertilization than it was the first year. The percentage of calcium in kudzu was not greatly affected by fertilization.
4. Cultivation was of value to eliminate competing vegetation during the early stages of the growth of the kudzu, but was of no value on well-established kudzu.

SEMINAL ROOT NUMBER IN CULTIVATED BARLEY[1]

Merritt N. Pope[2]

SEMINAL roots are those that appear during germination. Their primordia are present in the mature seed. They are also called "temporary roots" in contrast with the "permanent" ones, which, under favorable conditions, appear later at the crown and lower nodes. Under very unfavorable conditions, the seminal roots may be the only ones that ever become functional. Locke and Clark (3)[3] reported such a condition in wheat where a plant with nine culms was nourished entirely through the seminal roots.

In the cereals, the number of seminal roots varies greatly. Rice, sorghum, and proso have but one (8) and oats three. In the other common cereals, the number is variable, rye having "over 3", and Robbins (7) gives five to eight as the number in wheat and barley. In corn, Wiggans (9) found maxima of "over 8" in the dent and 7 in the flint and sweet varieties. Furthermore, Mangelsdorf and Goodsell (5) found that the number from kernels from the same ear were significantly peculiar to that ear, though those kernels from the butt gave the greatest number and those from the tip, the least.

In wheat, McCall (4) suggested that a maximum of 9 roots in the subcrown region of the plant may develop under optimum conditions. Three of these may arise above the point of attachment of the coleoptile and are regarded by him as adventitious, i.e., not present in the mature embryo.

Since Merry (6) found the unusually high number of 9 in the barley variety Alpha, it seemed worthwhile to measure the variability in seminal root number in barley as well as some of the factors influencing their number.

MATERIALS AND METHODS

Pure lines of representative barley varieties to the number of 73 were selected to provide a wide range of types, including differences in density of spike, seed color, size of seed, adherence of hull, and character of lemma tip. All four species as given by Harlan (2) as well as *Hordeum irregulare* E. Aberg and Wiebe (1) were represented. In addition, one sample of the wild species *Hordeum spontaneum* C. Koch and one six-rowed natural tetraploid were used. The varieties of the species *H. distichon* L., *H. intermedium*, and *H. vulgare* L. originally came from various widely separated regions and show wide differences in botanical characters and environmental response. The *H. deficiens* Steud. and *H. irregulare* varieties, however, probably all originated in Ethiopia, and, while they vary considerably in certain characteristics, they are markedly alike in many others.

The seed of the 73 varieties tested was produced in 1941 at Sacaton, Ariz., under very favorable conditions and the samples were almost uniformly good. In addition, 32 bulk samples of malting barley were obtained from Dr. J. G. Dickson of this Division from Madison, Wis. They comprised a group of 12 varieties, two of which had been grown at three places over a period of 3 years, two at one location for 3 years, and the remainder in single plantings. These were

[1]Contribution from the Division of Cereal Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture. Received for publication April 21, 1945.

[2]Agronomist.

[3]Figures in parenthesis refer to "Literature Cited", p. 778.

tested to determine the effect of environment and for possible relationships of seminal root development to malting quality.

Ten to 15 central kernels of each variety selected for uniformity of appearance were germinated on wet filter paper in petri dishes for 8 to 10 days at 15° C (69° F), constant temperature. Nonviable seeds or those noticeably weak in germination were rejected. For the study of the effect of stage of maturity on seminal root number, spikes of greenhouse-grown Manchuria barley harvested at daily intervals after hand pollination were used.

In certain seed lots results were checked microscopically in remnant ungerminated seeds by counting the roots in embryo sections after staining with haematoxylin and safranin.

EXPERIMENTAL RESULTS

SEMINAL ROOT NUMBER IN SPECIES AND VARIETIES OF BARLEY

The variation in number of seminal roots (Table 1) within a variety was very small. The primary and first two pairs were of almost universal occurrence and where more were found in a variety, those in excess of five varied considerably in point of origin. This condition resulted in a smaller variation in seminal root number in varieties showing a low number, i.e., five to seven roots. For example, the six *intermedium* varieties varied in average number from 5.6 to 7.7 with a group average of 6.47, while the range of variation in any individual variety was but 1 root. Likewise, the *vulgare* sorts ranged from 5.4 to 7.7 seminal roots with an average for the group of 6.39. Here there was no variation in two varieties and in 17, each had a range of 1 root. On the other hand, the *irregulare* group had the highest number, averaging 7.61 roots, where one variety did not vary, four had a range of variation of 1 root each, and six a range of 2 roots each. In this group, the average range of variation was 1.45 roots for each variety. In the *distichons* the variety average ranged from 5.6 to 8.9 seminal roots, a wide range probably associated with the diversity of their varietal origins. Here the eight varieties that had a range of variation of 1 seminal root averaged 7.18 roots, while the six varieties with a range of 2, averaged 7.83 seminal roots. The one

TABLE 1.—*Number of seminal roots in species and varieties of barley.*

Species	Varieties tested, No.	Seminal roots, av. No.	Number of varieties with intravarietal range of					Average number of roots in varieties within the group		
			0 root	1 root	2 roots	3 roots	Av. range	Minimum	Maximum	Range
H. deficiens	21	7.27	2	9	9	1	1.43	6.7	8.2	1.5
H. irregulare	11	7.61	1	4	6	—	1.45	6.8	8.3	1.5
H. distichon	14	7.40	—	8	6	—	1.43	5.6	8.9	3.3
H. intermedium	6	6.47	—	6	—	—	1.00	5.6	7.7	2.1
H. vulgare	19	6.39	2	17	—	—	0.89	5.4	7.5	2.1
H. spontaneum	1	4.7	—	1	—	—	—	—	—	—
Natural tetraploid, *H. vulgare*	1	6.8	—	—	1	—	—	—	—	—

variety of *H. spontaneum* with 4.7 as the average number of roots per seed had a range of but 1 root in the 12 seeds germinated.

The maximum average number of 8.9 seminal roots was found in two *distichon* varieties, *viz.*, White Smyrna (from Asia Minor) and Alpha. The latter is a segregate from a cross between the six-rowed variety Manchuria and Champion of Vermont, a two-rowed sort which came from Germany. Both parental varieties were among the 73 tested, Manchuria showing 6.8 roots and Champion of Vermont 6.7 seminal roots. However, these pure lines were probably not the ones used as parents of Alpha. Since this variety is many generations removed from the cross, the high root number is not a result of hybrid vigor such as that reported by Mangelsdorf and Goodsell (5) who found that during five generations of selfing in four strains of corn the seminal root number was consistently and progressively reduced. In six other varieties in the list that were of hybrid origin, the seminal root numbers were not noticeably high.

No relation is apparent in the data between seminal root number and the characters density of spike, color of seed, adherence of lemma, or character of lemma tip.

A doubled chromosome number as exhibited in a six-rowed natural tetraploid was not associated with an increase in seminal root number. This variety had 6.8 roots which is well within the range of the *vulgare* group which has an average of 6.39 seminal roots. As an additional check on varietal differences, 42 of the above 73 pure lines were grown in the greenhouse at Beltsville, Md., in the winter of 1943–44 and the seeds produced were germinated and their roots counted. These numbers were then compared with those obtained from the parental material. A seminal root number higher in all except 3 of the 42 lines was obtained from the seed grown in the greenhouse as compared with the same lines grown in the field at Sacaton. The highly significant correlation coefficient of +.773 obtained between the counts of the two sets shows clearly that seminal root number is a varietal character.

RELATION BETWEEN NUMBER OF SEMINAL ROOTS AND AREA OF ABSORPTIVE SURFACE OF SCUTELLUM

The scutella of different varieties vary considerably in area. Since it is the feeding organ of the embryo, a large scutellum might be expected to be associated with a more fully developed embryo. The under or absorptive surface area of the scutellum was measured approximately in eight varieties of barley by soaking five seeds of each, peeling out the germs, and outlining each scutellum on paper of uniform thickness by means of the camera lucida at a magnification of 20×. These outlines were then cut out and the papers weighed. The average area in square millimeters for each variety was then computed from the weight of a measured area of the paper. This calculated area is slightly less than the actual area because the absorptive surface of the scutellum is not flat but forms a "bulge" that extends into the endosperm. The bulge is not the same for all varieties, but the error introduced by this fact is believed not to be

large. In Table 2 are given the seminal root number, the area of the absorptive surface of the scutellum, and the depth of the "bulge" of each variety.

An insignificant negative correlation between seminal root number and absorptive area of the scutellum was found, r being -.287.

TABLE 2.—*Seminal roots and computed scutellar areas in eight varieties of barley.*

Variety	C. I. No.*	Average No. of seminal roots	Approximate area under side of scutellum, sq. mm.	Scutellum bulge
Alpha	959	8.9	6.426	Medium
Primus	2268	8.1	9.229	Distinct and large
Bethges Victoria	6616	6.9	8.367	Very slight
Hannchen	531	7.9	7.720	Evenly rounded
Intermedium	6029	7.7	12.489	Very slight
Manchuria	2330	6.8	8.133	Very slight
Wisconsin Barbless	5105	6.8	6.190	Nearly absent
Natural tetraploid	6123	6.8	9.889	Nearly absent

*Accession number of Division of Cereal Crops and Diseases.

EFFECT OF LENGTH OF FRUITING PERIOD AND OF SEED WEIGHT BETWEEN VARIETIES

As will be seen later, in a single variety, seed harvested before maturity evidences its immaturity by reduced seed weight as well as by a smaller number of seminal roots. Since barley varieties vary considerably in length of fruiting period and in seed weight, the relation between these two characters and seminal root number was studied. The relation between length of fruiting period and the number of seminal roots was tested in a comparison involving 35 varieties. Seeds were planted four to a pot in the greenhouse in the fall of 1943 and four spikes in each pot tagged at awn emergence, or, in the case of hooded, awnless, or short-awned varieties when the boot leaf spread far enough to make the spike visible. The date when the awns or lemma tips had lost all chlorophyl also was recorded and the average period between the two dates taken for the growth period of the seed of the variety. Correlation coefficients were then calculated between number of seminal roots and the length of developmental period. While the *vulgare* varieties showed a significant correlation, the results, as a whole, were inconclusive (Table 3).

Since a variety with larger seeds might be expected to bear larger, better developed embryos, the weights of plump, well-matured seeds from 26 *vulgare* and *distichon* varieties, all grown in 1941 at Sacaton, Ariz., were correlated with the number of seminal roots. Here again the results are inconclusive (Table 3), since the *vulgare* varieties gave a negative correlation, which, combined with a significance of $P = .05$ in the positive correlation shown by the *distichon* gave a seemingly significant correlation for both groups. The varieties studied varied greatly in point of origin and genetic content and, if correlations existed between seminal root number and these two

TABLE 3.—*Correlation of seminal root number with other characters.*

Character	Number of varieties	Character of population	Correlation with seminal root number (r)	Level of significance
Absorptive area of scutellum	8	Widely different as to species and sources of origin	−.287	None
Length of developmental period	14	*H. Vulgare*	.628	P =.02
	12	*H. distichon*	.170	None
	9	*H. intermedium, deficiens,* and *irregulare*	.421	None
	35	Total	.297	None
Weight of seed	13	*H. vulgare*	−.163	None
	13	*H. distichon*	.577	P =.05
	26	Total	.460	P =.02
Weight of seed	1	Wisconsin Barbless (9 samples) grown for 3 years at three places	.776	P =.02
Diastatic power	12	Malting barleys (30 samples)	.082	None
	1	Wisconsin Barbless (8 samples)	−.243	None
Wort nitrogen	12	Malting barleys (30 samples)	.305	None
	1	Wisconsin Barbless (8 samples)	−.375	None

characters, they seemingly should appear, or, at least, the results should be consistent. Notwithstanding the small number of varieties studied it would appear, therefore, that in well-matured barley seeds, the seminal root number is not associated with either the length of developmental period or the kernel weight of the different varieties.

RELATION OF STAGE OF MATURITY AT HARVEST TO NUMBER OF SEMINAL ROOTS

In the greenhouse during the winter of 1942–43, a series of spikes of Manchuria barley (C.I. 2330) was harvested daily, beginning 3 days after hand-pollination and continuing until growth of the seeds was completed. Three of the best-developed seeds from each spike were saved for microscopic examination and the remainder were germinated for 15 or 16 days at 10° C.

In Table 4, it is seen that the youngest seed to show evidence of viability occurred in spike No. 2 of the 11th day sample where, out of 15 seeds tested, 6 germinated with a maximum of 3 roots. However, only one seedling was alive at the end of the test. In subsequent samples the number of seminal roots increased with age to a maximum of 6 or 7 at 26 days after pollination. Spikes that showed increases in root number over the previous day's samples were noted and the three seeds from each that had been reserved were sectioned and the number of roots counted in each. In the 10-day samples,

2, 1, and 2 roots, respectively were found in the three seeds from spike No. 1, while only the primary root was found in those from spike No. 2. Similarly only 1 root was present in each of the seeds from spike one of the 11-day sample. As has been noted, spike No. 2 of the 11-day sample showed some germination and the sections showed 3 roots in each of the three seeds examined. This would indicate that 3 is the minimum number of seminal roots necessary for germination and that they should be well along in their development.

TABLE 4.—*Germination test of greenhouse-grown Manchuria barley (C.I. 2330) harvested daily beginning 3 days after pollination, showing the number of seminal roots increasing with age.*

Days after polli-nation	Spike No.	Number of seeds—		Number of seeds with following number of seminal roots							Number of seminal roots in each of three un-germinated seeds
		In sam-ple	Ger-mi-nated	1	2	3	4	5	6	7	
10	1	?	None	–	–	–	–	–	–	–	2, 1, 2
	2	?	None	–	–	–	–	–	–	–	1, 1, 1
11	1	?	None	–	–	–	–	–	–	–	1, 1, 1
	2	15	6*	2	1	3	–	–	–	–	3, 3, 3
12	1	17	17	–	–	17	–	–	–	–	3, 3, 3
13	1	17	12	–	2	9	1	–	–	–	2, 2, 3
	2	14	10	–	3	4	3	–	–	–	3, 3, 3
16	2	21	21	–	–	–	18	3	–	–	5, 5, 5
20	1	10	9	1	–	–	5	2	1	–	6, 6, 5
21	1	11	11	–	–	–	–	4	7	–	6, 6, 6
26	1	16	16	–	–	–	3	0	12	1	6, 6, 6
27	1	15	14	–	–	–	–	3	9	2	6, 6, 7
29	1	15	15	–	–	–	–	7	8	–	6, 7, 7

*At end of germination period (16 days) only one seedling was living. It had 3 roots.

The data from the 13-day samples suggest that seminal roots *may* arise during germination from primordia not identifiable in the ungerminated seed. However, for the present, it seems preferable to assume that the seeds sectioned had been poorly selected, since, in all other samples, the number of seminal roots as determined from sections agreed very well with the number in the portion of the samples germinated. Also, the maximum number, 7, in the sections of seed harvested 27 and 29 days after pollination agrees well with the average number of roots, 6.8, found in seed of this variety grown at Sacaton, Ariz.

Since, under unfavorable conditions of growth, the seed of a variety is markedly thinner and lighter than when grown under a favorable environment, the seed weight may be considered a measure of its stage of development at harvest. Such environmental effects are seen in nine samples of Wisconsin Barbless barley grown at three places over 3 years. The lighter, less well-matured seed showed progressive depression in seminal root number. The correlation coefficient for this pair of characters in the nine samples was found to be +.776, which is significant at the P = .02 level.

SEMINAL ROOTS IN BULK SAMPLES OF MALTING BARLEY

The seminal root numbers were determined for 30 of the 32 bulk barley samples obtained from Dr. Dickson, for which malting data were available, in order to learn whether this number is associated with malting quality. Fifteen kernels were taken at random from each sample and the lemmas removed from over the embryos. These samples were then weighed in mg, germinated for 8 days at 15° C, and the average number of seminal roots recorded for each sample after rejecting all seed showing weak or no germination but including shrunken seeds from which a low root number might be expected. By using, in addition, the eight samples of the single variety, Wisconsin Barbless, grown at three different places over a period of 3 years, the unconsidered variables were reduced in number, which should intensify the correlation if present. The coefficients of correlation were then found between seminal root number and (a) diastatic power and (b) percentage wort nitrogen, as shown in Table 3. All of the correlation coefficients are small and none is significant.

SUMMARY

In well-matured seeds of cultivated barley the average number of seminal roots of 72 pure-line varieties ranged from 5.4 in the six-rowed Winter Club to 8.9 in the two-rowed varieties Alpha and White Smyrna. Within a variety the number was relatively uniform, seldom varying by more than 2 roots among individual seeds. Because of the low variability within a variety and the high correlation between the same varieties grown under different environments, it appears that seminal root number is a varietal character. Within a species, the varieties of *H. distichon*, with the widest diversity of forms and sources of origin, ranged from 5.6 to 8.9 seminal roots. *H. deficiens* and *H. irregulare* both had a varietal range of variation of but 1.5 roots. The species *H. intermedium* and *H. vulgare* each had a varietal range of variation of 2.1 roots.

A single strain of a six-rowed natural tetraploid had an average of 6.8 roots, a number characteristic of the diploid varieties of the *vulgare* group. This indicated that doubling of the chromosome number did not affect the formation of seminal roots.

No association was apparent between seminal root number and density of spike, color of seeds, adherence of lemma and palet, or character of lemma tip.

The area of the absorptive surface of the scutellum of eight widely different varieties was not correlated with a seminal root number. Lack of consistently significant intervarietal correlations would indicate that in mature seed, seminal root number is independent of both the length of developmental period and seed weight.

Within a variety the number of seminal roots increases with number of days after pollination. In Manchuria barley the earliest viable immature stage showed 3 roots in sections and produced on germination a maximum of 3 roots. With further growth and development of the seed, the number increased to the maximum for the variety when the seeds were plump and well-matured. In nine field

samples of Wisconsin Barbless barley a correlation coefficient of .776 was found between kernel weight, as indicating stage of development at harvest, and number of seminal roots. This value is significant at the P = .02 level.

No correlation was found between number of seminal roots and malting quality as measured by diastatic power or by percentage of wort nitrogen produced in 30 samples of malting barley representing 12 varieties grown in 3 years at three different places. A similar lack of correlation was found among nine samples of the Wisconsin Barbless variety.

LITERATURE CITED

1. ÅBERG, EWERT, and WIEBE, G. A. Irregular barley, *Hordeum irregulare* nov. sp. Jour. Wash. Acad. Sci., 35:161–164. 1945.
2. HARLAN, H. V. The identification of varieties of barley. U.S.D.A. Bul. 622.
3. LOCKE, L. F., and CLARK, J. ALLEN. Development of wheat plants from seminal roots. Jour. Amer. Soc. Agron., 16:261–268. 1924.
4. MCCALL, M. A. Developmental anatomy and homologies in the wheat plant. Jour. Agr. Res., 48:283–321. 1934.
5. MANGELSDORF, P. C., and GOODSELL, S. F. The relation of seminal roots in corn to yield and various seed, ear and plant characters. Jour. Amer. Soc. Agron., 21:52–58. 1929.
6. MERRY, JAMES. Studies on the embryo of *H. sativum*. I. Development of the embryo. Bul. Torrey Bot. Club, 68:585–598. 1941.
7. ROBBINS, W. W. The Botany of Crop Plants. Ed. 3. Philadelphia; Blakiston. 1931.
8. SIEGLINGER, JOHN B. Temporary roots of the sorghums. Jour. Amer. Soc. Agron., 12:143–145. 1920.
9. WIGGANS, ROY G. The number of temporary roots in cereals. Jour. Amer. Soc. Agron., 8:31–37. 1916.

NOTES

SIZING WHOLE SUGAR BEET SEED TO IMPROVE GERMINATION

IN CONNECTION with the breeding work of the Holly Sugar Corporation at Sheridan, Wyo., low-germinating seed has frequently been encountered. The low-germinating seed arises largely as a result of small plantings of mother beet roots and stecklings which are space isolated in gardens in this area for seed production. The use of this low-germinating seed has been a problem which interfers with the breeding work and particularly the small plot variety testing program. Increased planting rates, hand plantings, transplanting, and other procedures have been utilized with limited success. Procedures for improving germination, such as the use of polishing machines, air separation devices, gravity tables, and cleaning machines, have all been tried with limited success. Investigations of germination qualities of fractional sizes of seed have given rise to the use of a procedure which has proved to be very useful and it is believed may prove of value to other workers.

The seed is all harvested, threshed, and cleaned in the customary manner. Each lot of seed is thoroughly mixed and a representative sample is used for germination. All seed lots having a germination below 70% are reworked to improve the germination. A sizing test is conducted using a representative sample of about 1 pound or the full amount of seed if less than 1 pound. The seed is divided into six sizes by a nest of six 12×12-inch hand screens. The nest contains a blank for the botton, 8/64, 9/64, 10/64, 11/64, and 12/64 inch round hole perforated screens. After the seed is graded over these screens, each fraction is weighed and a crack test is made of each fraction. A crack test consists of mashing 100 seeds and examining each seed for the presence of white starchy germ material. The number showing starch is referred to as the crack test. The difference between actual germination and the crack test is quite variable in different lots of seed and must be taken into account. This difference varies from zero up to as much as 30%. By examination of the weight and crack test of these fractions and the comparison of actual germination and the crack test of the original seed, a screen size for grading the seed is selected which will give the desired result.

In general, all seed below an 80 crack is discarded, but where the germination and crack test are close together a lower standard is sometimes used. If desired, weighted averages may be calculated and an estimate made of the germination of the final product as well as an estimate of the loss in weight for any size screen for each lot of seed. This is a desirable procedure for larger amounts of seed. For the average lot of seed there is usually a decided change in both the weight and crack test at a given size which can readily be located by examination of the data.

Table 1 presents the results obtained for 40 seed lots with original germinations of from 32 to 69% where all fractions below an 80 crack were discarded. The data show a progressive increase in crack

with an increase in size of seed. In all but one case, lot No. 4, the desired level of 70% germination was obtained by discarding all fractions below an 80 crack. It is to be noted that for some lots the germination was raised higher than necessary with a resulting greater loss of seed. This can be avoided by calculating the results before resizing as mentioned above. The data for the 40 seed lots show an

TABLE 1.—*Fractional sizing of whole sugar beet seed.*

Original seed			Fractional size crack test						% germination of sized seed	% loss in weight of seed	Gain in % germination
Lot No.	% germination	Crack test	Below 8/64	8/64 to 9/64	9/64 to 10/64	10/64 to 11/64	11/64 to 12/64	Above 12/64			
1	53	78	34*	51*	72*	84	89	95	70	16	17
2	68	88	47*	75*	82	90	97	98	74	7	6
3	54	83	46*	65*	76*	85	96	98	74	17	20
4	60	77	8*	31*	61*	63*	81	97	69	25	9
5	43	65	10*	31*	56*	72*	83	92	78	38	35
6	61	86	35*	55*	79*	88	96	98	90	17	29
7	63	93	70*	76*	91	96	99	100	88	10	25
8	63	85	34*	61*	75*	88	95	96	94	20	31
9	54	82	15*	44*	58*	64*	80	92	84	30	30
10	54	76	21*	41*	56*	72*	91	95	84	36	30
11	55	71	12*	39*	55*	69*	84	93	83	22	28
12	63	81	8*	54*	61*	70*	85	94	72	25	9
13	51	71	14*	33*	55*	80	83	89	85	43	34
14	65	84	32*	68*	77*	92	95	96	92	38	27
15	54	67	6*	30*	45*	61*	68*	83	78	62	24
16	48	76	13*	26*	51*	68*	85	91	86	11	38
17	61	77	9*	37*	46*	68*	91	95	90	44	29
18	56	75	23*	52*	76*	81	90	96	85	50	29
19	61	82	33*	63*	74*	88	93	95	86	43	25
20	56	72	30*	51*	69	86	87	96	82	47	26
21	62	79	41*	67*	85	88	92	97	84	38	22
22	63	79	15*	34*	55*	71*	81	92	76	17	13
23	68	84	32*	44*	67*	76*	84	93	80	21	12
24	60	80	41*	62*	80	81	92	96	86	11	26
25	62	88	69*	74*	83	90	93	98	91	9	29
26	60	66	6*	39*	70*	89	91	96	84	67	24
27	32	53	9*	36*	64*	81	87	94	80	73	48
28	65	74	2*	22*	47*	70*	85	91	86	67	21
29	61	78	42*	55*	71*	82	83	95	83	14	22
30	56	87	45*	66*	81	91	91	96	72	8	16
31	49	77	40*	54*	72*	77*	81	90	71	37	22
32	50	58	8*	17*	27*	48*	57*	86	87	45	37
33	43	61	2*	6*	19*	48*	60*	88	87	60	43
34	69	78	50*	71*	84	88	88	94	88	27	19
35	37	47	7*	28*	47*	62*	79*	88	82	79	45
36	62	79	15*	49*	75*	89	91	94	71	50	9
37	51	78	4*	19*	40*	74*	86	94	81	40	30
38	47	70	19*	52*	76*	90	93	95	88	60	41
39	54	65	4*	16*	38*	50*	80	90	72	43	18
40	66	82	11*	28*	62*	83	94	95	80	14	14
Av.	56	76	24	46	64	77	86	94	82	35	25

*Fraction discarded.

average germination of 56% for the original seed and 82% for the final resized product, with an average loss in weight of 35% and an average increase in germination of 25%.

We have applied this fractional testing and resizing procedure to over 500 lots of seed, including stock seed lots and commercial seed produced in other localities with satisfactory results in all cases. In all but a few cases of extremely low germinations, the results have been similar to those shown in Table 1. It is believed that the application of this procedure at the cleaning plants to commercial sugar beet seed produced in America will result in large savings in handling, storage, and transportation costs.—FRANK F. LYNES, *Holly Sugar Corporation, Sheridan, Wyoming.*

THE PERSISTENCE OF AMMONIA NITROGEN AGAINST LEACHING

RECENT tests to determine residual nitrogen in the soil after treatment with nitrogen carriers show that there may be a large carry-over of unused nitrogen when crop yields are reduced by moisture deficiency during the growing season.

Nitrogen was applied in late July and the soil samples were collected the following April. From the area receiving sulfate of ammonia 60 p.p.m. of ammonia nitrogen and 10 p.p.m. of nitrate nitrogen were recovered. The area to which nitrate of soda was applied tested 10 p.p.m. ammonia nitrogen and 5 p.p.m. nitrate nitrogen. The crop was cabbage and the rate of nitrogen application was 125 pounds of nitrogen per acre. The August-September rainfall was 3 inches. The precipitation between October and the time of sampling in late April was 20 inches. Water lost as runoff was largely the result of spring thaw. The total runoff between October and the time of sampling the soil as measured on an adjacent area similarly cropped was 5.76 inches. The soil was a Dunkirk silty clay loam with pH of 5.6 to 6.0.—EVERETT A. CARLETON, *Soil Conservation Experiment Station, U. S. Dept. of Agriculture, Geneva, N. Y.*

BOOK REVIEW

PLANTS AND PLANT SCIENCE IN LATIN AMERICA

Edited by Frans Verdoorn. Waltham, Mass.: Chronica Botanica Co.; New York: G. E. Stechert and Co. XI+384 pages, illus. 1945. $6.

THIS Volume XVI in a new series of plant science books has been planned as an aid to better inter-American relations as well as a useful compendium of information, botanical, economic, agronomic, ecological, phytogeographic, and historical, for anyone interested in any aspects of Latin American botany. The editor has assembled nearly a hundred contributions from authoritative writers dealing with each of the political entities of Latin America. These are mostly written in English, but Spanish, French, and Portuguese are also represented. The book is attractively illustrated with 83 plates and text illustrations, many of which are reproduced from classical

June 15, 1945, by the Iowa State College of Agriculture and Mechanic Arts, Ames, Iowa, for outstanding contributions to agriculture. Doctor Stanton has been the leader for nearly 25 years of a group of scientists in a cooperative program of oat improvement with state stations which has resulted in the breeding and distribution of new disease-resistant and more productive varieties of oats for the Corn Belt and nearly all other sections of the United States. These varieties have made oats a much more certain and satisfactory crop at a time when the increased production of additional feed units for farm animals has been so essential to the winning of the war.

—A—

DOCTOR W. S. GILLAM, professor of agricultural chemistry at Purdue University, Lafayette, Ind., has joined the staff of the Midwest Research Institute, Kansas City, where he will specialize in research in soils, plant nutrition, and analytical services. He was formerly on the faculty of Michigan State College, East Lansing, Mich.; and Nebraska Wesleyan University and University of Nebraska, Lincoln, Nebr.

—A—

OREN BOLIN, Assistant Professor of Plant Genetics, Agronomy Department, University of Illinois, resigned September 1, 1945, and has accepted a position as Director of Research for the L. L. Lowe Seed Company, Aroma Park, Ill.

—A—

DOCTOR J. F. FUDGE succeeded Dr. G. S. Fraps as Chief of the Division of Chemistry and State Chemist of Texas when the latter retired on August 31, 1945. Doctor Fudge received the B. S. degree in agronomy at the University of Illinois and the Ph. D. degree in soil chemistry at the University of Wisconsin. Before coming to Texas, he was employed as a chemist at the Alabama and Florida agricultural experiment stations. He has been connected with the Division of Chemistry of the Texas Agricultural Experiment Station since 1929.

—A—

DOCTOR M. T. HENDERSON, formerly a member of the Division of Agronomy and Plant Genetics, University of Minnesota, has accepted a position as Associate Professor in the Department of Agronomy at Pennsylvania State College.

JOURNAL

OF THE

American Society of Agronomy

VOL. 37 OCTOBER, 1945 NO. 10

NUTGRASS ERADICATION STUDIES: IV. USE OF CHICKENS AND GEESE IN THE CONTROL OF NUTGRASS, *CYPERUS ROTUNDUS* L.[1]

E. L. MAYTON, E. V. SMITH, AND DALE KING[2]

NUTGRASS is recognized as a noxious weed of cultivated fields throughout its range. Although the plant produces some viable seed in the tropics, underground tubers constitute its principal reproductive organ, and appear to be its only effective one in the southeastern states. The tubers are carried to new areas by various means and produce new centers of infestation. From these centers the weed spreads by vegetative reproduction, and, in early stages of infestation, it usually occurs as small patches. Tubers from these patches may be carried throughout the field by tillage implements and soon may cause a general infestation.

Several workers, notably Andrews (1, 2),[3] Ranade and Burns (3), and Smith and Mayton (4, 5), have developed tillage methods for controlling or eradicating nutgrass. As a part of a project dealing with the control of nutgrass at the Alabama Agricultural Experiment Station, experiments were conducted to determine if the weed could be eradicated by grazing with chickens and with geese. It is generally recognized that chickens tend to destroy herbaceous vegetation near poultry houses. Geese are close grazers, and their use to help control grass in cotton fields was an early practice in the South.

GRAZING EXPERIMENTS WITH CHICKENS

SMALL PENS

A series of five 1/60-acre (25 by 29 feet) pens were fenced on an area infested with nutgrass. Earlier experiments (4) had shown that tuber counts give a more accurate record of nutgrass infestation than do sprout counts. Consequently, the original infestation in each individual pen was measured by screening out and counting

[1]Contribution from the Department of Agronomy and Soils, Botany and Plant Pathology, and Poultry Husbandry, Alabama Agricultural Experiment Station, Auburn, Ala. Published with the approval of the Director. Received for publication February 2, 1945.

[2]Formerly Associate Agronomist and Associate Botanist and Poultry Husbandman, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 791.

the live tubers from six 2- by 2-foot diggings. These data indicated that, although the infestation was heavy in all pens, it was variable from pen to pen.

The number of chickens in the pen was adjusted according to the nutgrass infestation as follows: Pen 1, 29.75 tubers per square foot, 3 chickens; pen 2, 19.25 tubers per square foot, 4 chickens; pen 3, 20.50 tubers per square foot, 8 chickens; pen 4, 18.50 tubers per square foot, 16 chickens; pen 5, not grazed.

Thus, if three chickens in pen 1 represented one rate of stocking, then 4, 8, and 16 represented the double, quadruple, and octuple rates, respectively, based on infestation. These rates of grazing were continued during two consecutive growing seasons. Final infestation records were obtained by digging approximately one-fourth of each plot and removing and counting the live tubers. The results are recorded in Table 1.

TABLE 1.—*Reduction in infestation of nutgrass on small plots from different rates of grazing by hens.*

Pen No.*	Rate of grazing	Number of hens	Number of live tubers per 2- by 2-foot section†			Number of live tubers in ¼ of pen, April, 1937
			Original, Apr. 1935	End 1st season, Dec. 1935	End 2nd season, Nov. 1936	
1	Single	3	119	170.6	54.0	1,761
2	Double	4	77	4.5	0.0	0
3	Quadruple	8	82	0.5	0.0	0
4	Octuple	16	74	0.5	0.0	0
5	Ungrazed	0	117	77.7	89.0	1,811

*Each pen was 1/60 acre in area.
†Average of six diggings.

White Leghorn cockerels were placed in the pens on April 9, 1935. Since they did not eat many of the nutgrass leaves, the cockerels were replaced by White Leghorn hens on April 15. The hens began eating the nutgrass leaves almost as soon as they were placed in the pens, and they were used during the remainder of the 1935 growing season and throughout the 1936 growing season.

The pens were observed at approximately weekly intervals during both growing seasons, and a record was made of the extent to which the chickens in each pen ate the leaves. At the quadruple and octuple rates, the hens were sufficiently numerous to become effective in the control of nutgrass early in the 1935 growing season. The hens ate most of the leaves within a week after they were placed in the pens. Due to basal growth of the leaves, "stumps" of nutgrass were present in the pens during the next month; in addition, an occasional new sprout was seen. Not a sprout or "stump" of nutgrass could be found in these pens on May 20, 1935, and this condition prevailed throughout the remainder of the growing season. It was apparent that the chickens were eating the nutgrass leaves

as rapidly as they were appearing. All other plants except coffee weed, *Cassia* sp., were eaten at the quadruple rate of stocking and even this weed disappeared at the octuple rate. The hens scratched the surface soil of both pens, isolating many nutgrass tubers that subsequently died. The pens were stocked with the same number of hens during the 1936 growing season, but not a single nutgrass sprout was observed in either pen during the entire season.

The double rate of stocking was slower in effecting control of nutgrass than were the higher rates. Although the hens "pecked off" most of the nutgrass leaves within a week after they were placed in the pen in 1935, they did not keep the "stumps" eaten to the ground until near the end of the growing season. There was a progressive decrease in the number of "stumps" until August 31, after which none was observed. No nutgrass sprouts or "stumps" were seen in this pen during the 1936 growing season.

The single rate of stocking was not effective in controlling nutgrass. The hens were not sufficiently numerous to eat the leaves as fast as they grew. Actually, the old, tough leaves over a large portion of the pen were not bothered by the hens during either growing season.

LARGE PEN

The results of grazing small pens with hens indicated that chickens may effectively control nutgrass. Consequently, a larger pen, ½ acre in area, was used in 1938. Three hundred White Leghorn hens were placed in the pen at the beginning of that growing season. Although there was some mortality of the hens, more than 200 remained in the pen throughout the season. They were housed in four range shelters, one near the center of each quarter of the pen. The hens appeared to be controlling the nutgrass during the first month, but they were ineffective during the remainder of the growing season. They kept the nutgrass leaves eaten to the ground around the shelters and near the shade cast by a permanent house at one end of the pen, but they did not graze effectively over the entire area.

The nutgrass infestation was determined by making tuber counts at the beginning and end of the growing season. In the spring three 2-foot wide trenches were dug along the long axis of the pen and three along the short axis. The soil was removed in 4-foot segments and the tubers were sifted out and counted. In the fall six trenches were dug adjacent to the spring diggings, and the tubers were removed and counted. The results are given in Table 2. Instead of a decreased infestation at the end of one season of grazing, there appeared to be a several-fold increase.

It is evident that, although chickens may eradicate nutgrass from small areas, they are ineffective in larger areas.

GRAZING EXPERIMENTS WITH GEESE

GOOSE PEN

A ½-acre pen, heavily infested with nutgrass, was grazed by eight geese during the 1938 and 1939 growing seasons. Infestation records

were determined in the same manner as in the larger chicken pen. The results are summarized in Table 2.

TABLE 2.—*Effect of infestation of nutgrass in uncropped ½-acre plots when grazed by chickens and by geese, and in ½-acre plots cropped to cotton and grazed by geese.*

Treatment	Number of live tubers per 2- by 2-foot section		
	Beginning 1st season	End 1st season	End 2nd season
Uncropped, grazed by 300–200 hens	108.4*	514.0*	....‡
Uncropped, grazed by 8 geese	43.6†	89.6†	131.3†
Cropped to cotton, grazed by geese (16 in 1938, 4 in 1939)	109.9†	39.7†	5.1†
Cropped to cotton, grazed by geese (16 in 1939, 4 in 1940)	589.6*	124.5*	0.0§

*Represents average number of tubers from 192 diggings.
†Represents average number of tubers from 258 diggings.
‡Discontinued after one season.
§In addition, 55 2- by 2-foot diggings were taken at random over the plot. No live tubers were found, but the dead tubers averaged 59.6 per digging.

There was an average of 43.6 live tubers per 2- by 4-foot segment of trench at the beginning of the first season of the experiment, 89.6 at the end of the first season, and 131.3 at the end of the experiment. Thus, it is apparent that the geese were not effective in the eradication of nutgrass in large areas.

PEN NO. 1 CROPPED TO COTTON AND GRAZED WITH GEESE

A ½-acre area heavily infested with nutgrass was planted to cotton in 1938. The cotton was chopped and sided, but was not cultivated thereafter. The laborers who chopped the cotton reported the worst nutgrass infestation that they had ever encountered. Sixteen geese were placed in the half-acre area in June and provided the only "cultivation" during the remainder of the season. The geese tended to follow the middles while feeding and to eat the nutgrass leaves to the ground as they went. As a result, very few nutgrass sprouts could be found in the area in September.

The nutgrass infestation was so greatly reduced in 1938 that only four geese were placed in the area which was again planted to cotton in 1939. Very few nutgrass sprouts were found at any time during the 1939 season.

The nutgrass infestation was determined at the beginning of the experiment and at the end of both growing seasons by the same procedure as used for the uncropped pen grazed by geese (Table 2). There was an average of 109.9 live tubers per 2- by 4-foot digging at the beginning of the experiment, 39.7 at the end of the first season, and 5.1 at the end of the experiment. Only an occasional sprout was found in the area the year following the conclusion of the experiment.

PEN NO. 2 CROPPED TO COTTON AND GRAZED BY GEESE

The results from pen No. 1 were so encouraging the first year that the ½-acre pen which had been grazed by chickens in 1938 was planted to cotton in 1939 and 1940, and was grazed by geese as a duplicate experiment. Sixteen geese were used in 1939 and four in 1940. As in the previous experiment, the cotton was not cultivated after it was chopped and sided.

The competition from nutgrass was so keen early in 1939 that an irregular stand of cotton resulted. Very few nutgrass sprouts were evident toward the end of the 1939 growing season. Nutgrass plants were so sparse in 1940 that they did not reduce the stand of cotton.

GENERAL DISCUSSION

The fact that the chickens eradicated nutgrass from the 1/60-acre pens, but were ineffective in the ½-acre pen requires some explanation. It also raises the question as to how large an area can be freed of nutgrass by grazing with chickens.

The difference in effectiveness of chickens in small and large pens lies largely in the habits of this fowl. It is commonly observed that chickens graze oats or other green feed most heavily in the vicinity of the poultry house, and that they do not graze generally over a wide area. All parts of the small pens were sufficiently near the shelter for the hens to range over and graze the nutgrass closely. In the larger pen, however, the hens grazed effectively only the areas near the shelter and in the shade of a permanent house near one end of the pen. They did not range over and graze the entire area.

General observation would indicate that chickens would more uniformly graze a square area than they would a long, narrow one. Seldom do chickens completely bare the ground more than 50 feet from the house, and it is doubtful if they would eradicate nutgrass over so wide an area. There are also differences in grazing efficiency of individual flocks, depending on how they have been previously handled. Chickens that have been kept on full feed in close quarters do not graze as freely as farm-raised birds that have become accustomed to obtaining a considerable portion of their food by foraging. Active, nervous breeds of chickens, such as White Leghorns, usually graze farther from the house than do the heavier, more sluggish breeds, such as Rhode Island Reds or Plymouth Rocks.

Based on the foregoing results and observations, if chickens are to be used for the eradication of nutgrass, they should be penned on relatively small areas probably not more than 50 feet square, they should be sufficiently numerous to keep the soil bare of nutgrass leaves, and they should be range hens preferably of the more active breeds.

The difference between the effectiveness of geese in the uncropped pen and in the pens planted to cotton also requires some explanation. The differences here lie partly in the habits of the goose and partly in the growth habits of nutgrass. The geese tended to range more widely over cropped than uncropped land. They tended to follow the cotton middles and to eat nutgrass leaves as they went.

Thus, they were more effective in the cropped pens than in the uncropped areas.

The growth habits of the nutgrass plant probably are of greater significance in explaining the greater effectiveness of geese in the cropped pens than are the feeding habits of geese. The nutgrass plant includes a system of underground tubers connected by rhizomes. The tubers contain a large amount of stored food. When the underground system is undisturbed, many of the tubers fail to produce leaves. In addition, undisturbed plants in dry weather tend to produce small, tough leaves which are not readily eaten by geese. Tillage operations used in preparing the land for cotton break up the nutgrass systems and isolate many of the tubers. Isolated tubers in the cropped pens sprouted, and, as the result, the nutgrass was more readily starved by the grazing geese. Moreover, the leaves of the nutgrass were more succulent and hence more palatable in the cropped than in the uncropped pens.

Competition from the cotton did not have a significant role in the greater reduction of nutgrass in the cropped plots. Nutgrass sprouts were found more commonly in the row than in the middle, indicating that they were overlooked by the geese and nullifying any argument that competition from the cotton was a major factor in destroying nutgrass.

The foregoing indicates that chickens may be used for the eradication of nutgrass from very small areas, but that they are not effective on larger infested areas. If poultry are to be used to control nutgrass on larger areas, geese should be used and only on cropped land. The combination of geese and cotton in controlling nutgrass has several advantages and disadvantages. The principal advantage is that nutgrass can be nearly eradicated from relatively large areas with minimum tillage. Another advantage is that only one or two pairs of mated geese need be carried through the winter. From them enough young geese can be raised in the spring to use in the eradication of nutgrass from ½-acre of land. Sale of geese in the fall may partially pay for the eradication. If the land is heavily infested with nutgrass, a poor stand of cotton can be expected the first year. The second year, however, a satisfactory stand should be obtained.

There are two principal disadvantages to the goose-cotton combination. The first is that the area must be fenced and the wings of the geese must be cropped occasionally to keep them on the area. The second is that the geese reduce the stand of nutgrass to such an extent that a grain supplement must be fed to keep the geese from starving.

SUMMARY

1. Cockerels were not effective in controlling nutgrass.
2. Hens eradicated nutgrass from small areas (1/60 acre) when they were sufficiently numerous to keep the nutgrass leaves eaten to the ground.
3. Hens were not effective in eradicating nutgrass from areas as large as ½-acre.
4. Geese were not effective in the control of nutgrass on uncropped areas as large as ½-acre.

5. Geese effectively controlled nutgrass in ½-acre pens when the areas were cropped to cotton. The cotton was not cultivated after it was sided.

6. In the pens grazed by geese, very little cultivation of the cotton was required.

7. Geese had to be given grain in the goose-cotton pens after nutgrass became scarce.

8. Sale of geese and cotton largely defrayed the expenses involved in controlling nutgrass by the goose-cotton method.

LITERATURE CITED

1. ANDREWS, F. W. A study of nutgrass (*Cyperus rotundus* L.) in the cotton soil of the Gezira. Ann. Bot., 4:177–194. 1940.
2. ————. The control of nutgrass in the Sudan Gezira. Emp. Jour. Exp. Agr., 8:215–222. 1940.
3. RANADE, S. B., and W. BURNS. The eradication of *Cyperus rotundus* L. Mem. Dept. Agr. India, 13:99–192. 1925.
4. SMITH, E. V., and E. L. MAYTON. Nutgrass eradication studies: II. The eradication of nutgrass, *Cyperus rotundus* L., by certain tillage treatments. Jour. Amer. Soc. Agron., 30:18–21. 1937.
5. ————, ————. Nutgrass eradication studies: III. The control of nutgrass, *Cyperus rotundus* L. on several soil types by tillage. Jour. Amer. Soc. Agron., 34:151–159. 1942.

COMPOSITION OF PEANUT SHELLS OF FILLED AND UNFILLED FRUITS AS AFFECTED BY FERTILIZER TREATMENTS[1]

W. E. COLWELL, N. C. BRADY, AND J. R. PILAND[2]

THE abortion of ovules in peanut fruit is largely responsible for the failure to attain the maximum productive capacity of a peanut plant. Even under soil conditions where high yields were obtained, it has been found that not more than three-fourths of the fruits contained two well developed ovules (3).[3] Yields of Virginia-type peanuts as high as 1,603 pounds per acre have been obtained even though abortion occurred in 61.1 % of the ovarian cavities (3). Thus, information on the factors affecting ovule abortion as well as the physiological processes which take place when peanut fruit develop are seen to be of utmost importance.

In previous investigations, Colwell and Brady (1, 3) found that nutrient supply was one of the factors affecting ovule development. Under conditions of high calcium supply abortions occurred less frequently, whereas additions of potassium and magnesium slightly decreased kernel development. Although none of the nutrient combinations employed were effective in producing only well filled fruit, it is evident that the failure of kernels to develop was at least in part a nutritional problem in which calcium played a vital role. Thus, it would seem that information on the chemical composition of the peanut fruit would be valuable in determining the mechanism whereby nutrient supply influences kernel development.

In the present study, particular attention was given to the peanut shell since previous work had shown the composition of this plant part to be more sensitive to nutrient supply than that of the kernel. Determinations were made for total nitrogen, potassium, magnesium, and calcium. In an attempt to associate chemical composition more directly with ovule abortion, separate analyses were made on shells of filled and unfilled fruit.

The experimental material on which analyses were run was obtained from field experiments in which fertilizer treatments had exerted pronounced effects on ovule development. Thus, it was possible to determine the effect of treatment on the composition of shells of filled and unfilled fruit, and to interpret these results in the light of the quality of fruit resulting from these same treatments.

MATERIALS AND METHODS

At the time of digging, fruits from 10 to 20 plants were detached from the vines, brought to the laboratory, and, after drying, were classified on the basis of kernel development. The classification procedure was used in determining the effect of treatment on fruit quality and has been described in detail elsewhere (3). To

[1]Contribution from the Department of Agronomy, North Carolina Agricultural Experiment Station, Raleigh, N. C. Published with the approval of the Director as Paper No. 211 of the Journal Series. Received for publication March 21, 1945.

[2]Associate Agronomist, Assistant in Agronomy, and Associate Soil Chemist, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 805.

obtain samples for analysis, the shells from 2-cavity size fruit, mature and free from disease, were separated from the remainder and divided into three groups, *viz.*, those containing two, one, and zero well-developed kernels. Throughout the study shells from these categories are referred to as 2-kernel, 1-kernel, and 0-kernel shells, respectively.

Shell samples were obtained from five field experiments conducted in the Coastal Plain area of North Carolina. In certain of these, only the shells from plots of selected treatments were analyzed. A summary of the treatments from which samples were taken is given in Table 1, and soil analyses are presented in Table 2. Shell samples from Virginia Bunch, N. C. Runner, Spanish 2B, and White Spanish varieties were obtained at locations RPF and FWR, Virginia Bunch only at locations MLW and WAT, and Jumbo Runner only at location ENE. The effects of treatments on the yield and quality at all locations have been

TABLE 1.—*Treatment designations and descriptions at each of five locations.*

Treatment designation	Source	Rate in lbs. per acre	Placement
		Location MLW	
O-O	No treatment	No treatment	One half placed 3–5 inches below seed at planting; one half on the row at early bloom
K-K	K_2SO_4	96 lbs. K_2O	
Mg-Mg	$MgSO_4 \cdot H_2O$	30 lbs. MgO	
Ca-Ca	$CaSO_4 \cdot H_2O$	800 lbs.	
		Locations RPF and FWR	
O	No treatment	No treatment	
G	$CaSO_42 \cdot H_2O$	400 lbs.	On foliage at early bloom
K	KCl	45 lbs. K_2O	Top dressed at emergence
L	Dolomitic lime	400 lbs.	In row at planting
		Locations WAT and ENE	
Ck	No treatment	No treatment	
G	$CaSO_4 \cdot 2H_2O$	400 lbs.	On foliage at early bloom
K	KCl	48 lbs. K_2O	In row at planting
L	Dolomitic lime	400 lbs.	In row at planting

TABLE 2.—*Soil types and certain chemical characteristics of the soils on which the experiments were conducted.*

Location and soil type	Soil analyses						
	pH	Base exchange capacity, M.E. per grams	Exchange Ca, M.E. per 100 grams	Exchange Mg, M.E. per 100 grams	Exchange K, M.E. per 100 grams	P, p.p.m.	Organic matter, %
(MLW)* Kalmia loamy sand	5.3	3.13	0.50	0.27	0.12	61	1.1
(RPF) Norfolk loamy sand	4.7	2.34	0.21	0.17	0.04	34	0.9
(FWR) Norfolk sand	4.6	1.98	0.54	0.21	0.04	29	1.0
(WAT) Ruston sandy loam	5.5	2.57	0.68	0.22	0.07	31	.9
(ENE) Dunbar-Lenoir fine sandy loam	5.5	3.24	1.39	0.29	0.08	60	1.2

*Initials of cooperative grower used to designate location.

presented in detail elsewhere (1, 3, 4) and will be discussed here only as a means of interpreting the analyses obtained.

ANALYTICAL METHODS

Exchange properties of the soils were determined by an ammonium acetate procedure (A.O.A.C.) and are expressed as M.E. per 100 grams of soil. Phosphorus was extracted by 0.002 N H_2SO_4 (Truog), and organic matter was determined by dry combustion (A.O.A.C.). The reported data are average values from four separate samples, each of which consisted of 20 portions of soil from the plow layer of the unfertilized plots.

After the separation of the shells as described above, they were ground to pass through a 40-mesh sieve and all analytical determinations were made on an air-dry basis. Nitrogen analyses were made according to the A.O.A.C. method for total nitrogen, including nitrates, and the nitrogen contents are expressed in this paper in terms of per cent.

The mineral constituents of the shells were all determined by A.O.A.C. methods. Total calcium contents were obtained by using the oxalate-permanganate procedure for plant material. The gravimetric pyrophosphate procedure was used in making the magnesium analyses, while potassium was determined gravimetrically as the chloroplatinate. All mineral constituents are expressed in this paper as M.E. per 100 grams of air-dry tissue.

RESULTS AND DISCUSSION

NITROGEN, POTASSIUM, AND MAGNESIUM CONTENTS OF SHELLS AS AFFECTED BY TREATMENT

Data presented in Fig. 1 show the nitrogen, potassium, and magnesium contents of 2-, 1-, and 0-kernel shells of the Virginia Bunch variety. Two of the most outstanding features of the data are (a) that the contents of the three constituents were all significantly higher in shells containing zero developed kernels than in shells in which both kernels developed, the levels of these constituents in the 1-kernel shells being intermediate; and (b) that the contents of these elements in a given shell group were not greatly affected by treatment. This lack of treatment influence is of particular significance since the treatments were widely different and consequently exerted markedly different effects on yield and kernel development (1). For example, the yield resulting from the calcium treatment (Ca) was more than double that obtained with no treatment (Ck); yet the composition of the shells in a given kernel group was unaffected by the calcium treatment.

This relationship between the number of well-developed kernels contained in a given shell and its composition was found to be essentially the same at four other locations where large type peanuts were grown. In the presentation of these data in Fig. 2, only the averages of all treatments are used since the effect of treatment, as illustrated in Fig. 1, was of minor significance.

Although there is considerable variation from experiment to experiment in the absolute values, the inverse relationship between fruit filling and the contents of the three constituents is apparent at all locations. Evidently this relationship is not greatly affected by soil environment for the soils on which the experiments were conducted varied considerably in their exchange properties (Table 2) and yields obtained without treatment varied from 271 to 1,499 pounds per acre.

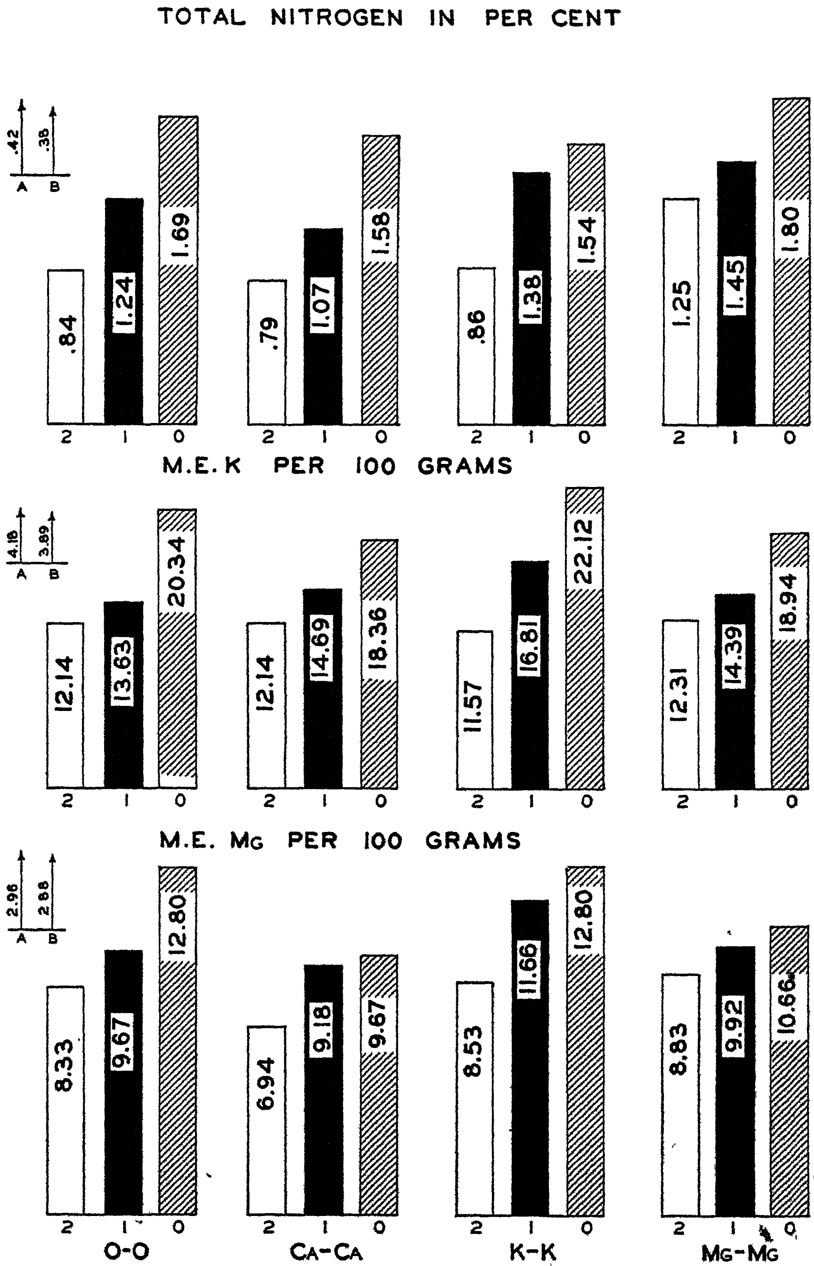

FIG. 1.—Nitrogen, potassium, and magnesium content of 2-, 1-, and 0-kernel shells as affected by treatment. (See Table 1 for treatments designated as O-O, Ca-Ca, K-K, and Mg-Mg resp. from left to right. Location MLW.) A = L.S.D. (.01) for comparing kernel values at a given treatment level; B = L.S.D. (.01) for comparing treatment values at a given kernel level.

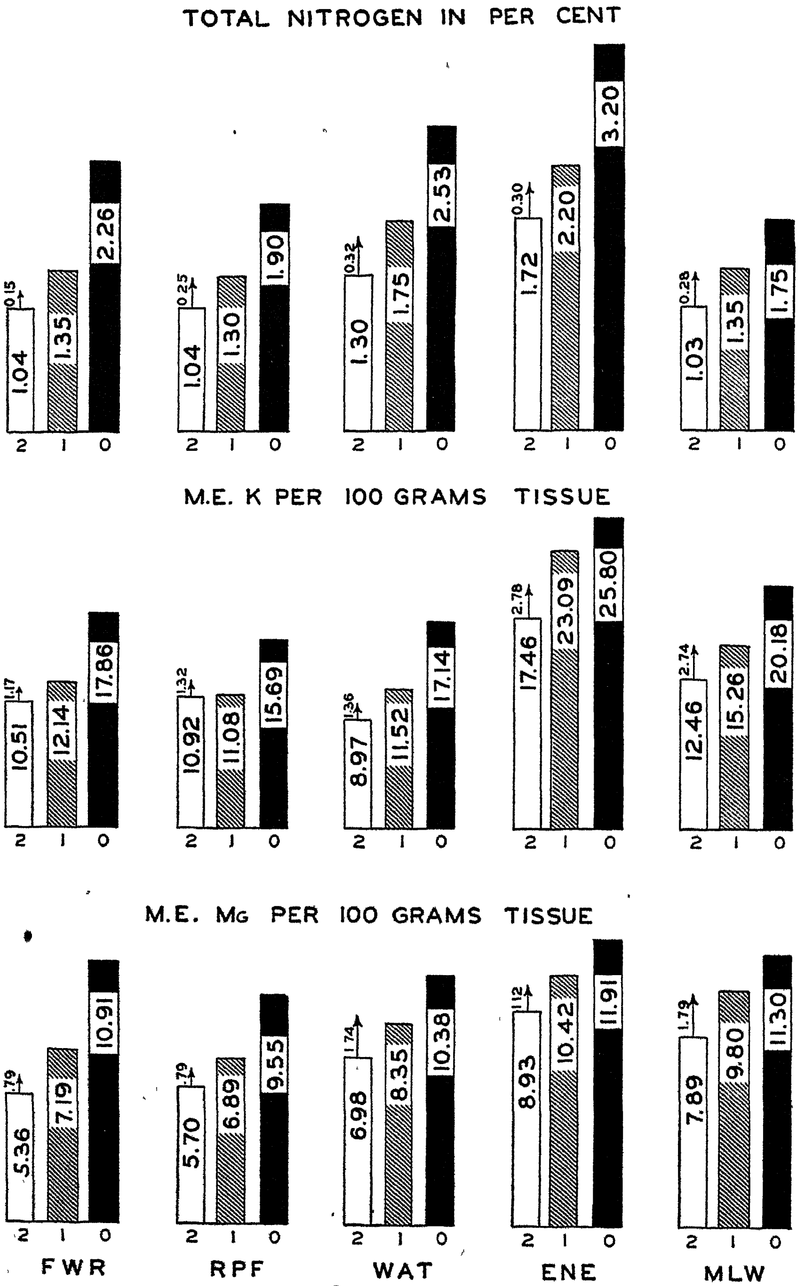

FIG. 2.—Relationship between fruit filling and nitrogen, potassium and magnesium contents of Virginia Bunch shells at five locations. 2, 1, and 0 = number of well-developed kernels contained per shell. L.S.D. (.01) values indicated by arrows.

Since at two locations, N. C. Runner, Spanish 2B, and White Spanish varieties were compared, data are available to show the effects of treatment and kernel development on the shell composition of these varieties and to compare them directly with those already noted on Virginia Bunch. The contents of nitrogen, potassium, and magnesium of shells from the no treatment and the gypsum plots at one location (FWR) are presented in Fig. 3. The corresponding data from location RPF are presented in Table 3.

TABLE 3.—*Nitrogen, potassium, and magnesium contents of shells of four varieties of peanuts as affected by calcium treatment and kernel development (RPF).**

Shell type	Without treatment				With gypsum				L.S.D. (.05)†
	Va. Bunch	N.C. Runner	Spanish 2B	White Spanish	Va. Bunch	N.C. Runner	Spanish 2B	White Spanish	
				Per Cent Nitrogen					
2-kernel	1.09	1.27	1.05	1.18	1.01	1.25	0.93	1.04	
1-kernel	1.66	1.26	1.33	1.67	1.41	1.34	1.17	1.21	a = 0.59
0-kernel	1.82	1.91	2.02	2.56	1.80	2.00	1.99	2.09	b = 0.63
				M.E. K per 100 grams					
2-kernel	8.07	8.92	11.46	15.07	5.73	12.53	13.16	17.20	
1-kernel	9.55	9.13	10.19	15.71	7.86	12.10	12.10	16.35	a – 3.00
0-kernel	10.40	14.22	16.14	21.66	10.62	17.41	19.11	22.93	b – 8.66
				M.E. Mg per 100 grams					
2-kernel	7.19	5.95	5.46	5.95	5.95	4.96	4.46	4.96	
1-kernel	8.68	5.95	6.45	7.94	6.45	6.45	5.95	6.94	a = 1.88
0-kernel	9.67	9.42	10.42	11.90	7.94	8.43	9.92	9.92	b = 1.98

*Values are averages from duplicate samples each of which was a composite from two replications.
†a = L.S.D. for comparing kernel group values at given treatment level; b = L.S.D. for comparing treatment values in a given kernel group.

As with Virginia Bunch, the contents of these elements in the shells increased as the number of well-developed kernels per shell decreased. In general, the calcium treatment had no effect on the composition of shells with a given number of well-developed kernels. One exception was the tendency for the calcium treatment to result in a lower nitrogen content of 0-kernel shells of the Spanish varieties, especially Spanish 2B.

Varietal differences were not pronounced, although in general the potassium contents of shells of the Spanish varieties were somewhat higher than those of Virginia Bunch or N. C. Runner. The magnesium content in shells of N. C. Runner were somewhat lower than that found in shells of the other varieties.

Since, as previously noted, treatment markedly affected kernel development, it is of interest to know how the composition of shells of a bulk sample of 2-cavity size fruit would be affected by treatment. Data are available from one location (MLW) to provide information on this point. In considering these data, which are pre-

sented in Fig. 4, the fact should be kept in mind that the samples were not field run since 1- and 3-cavity size shells were not included.

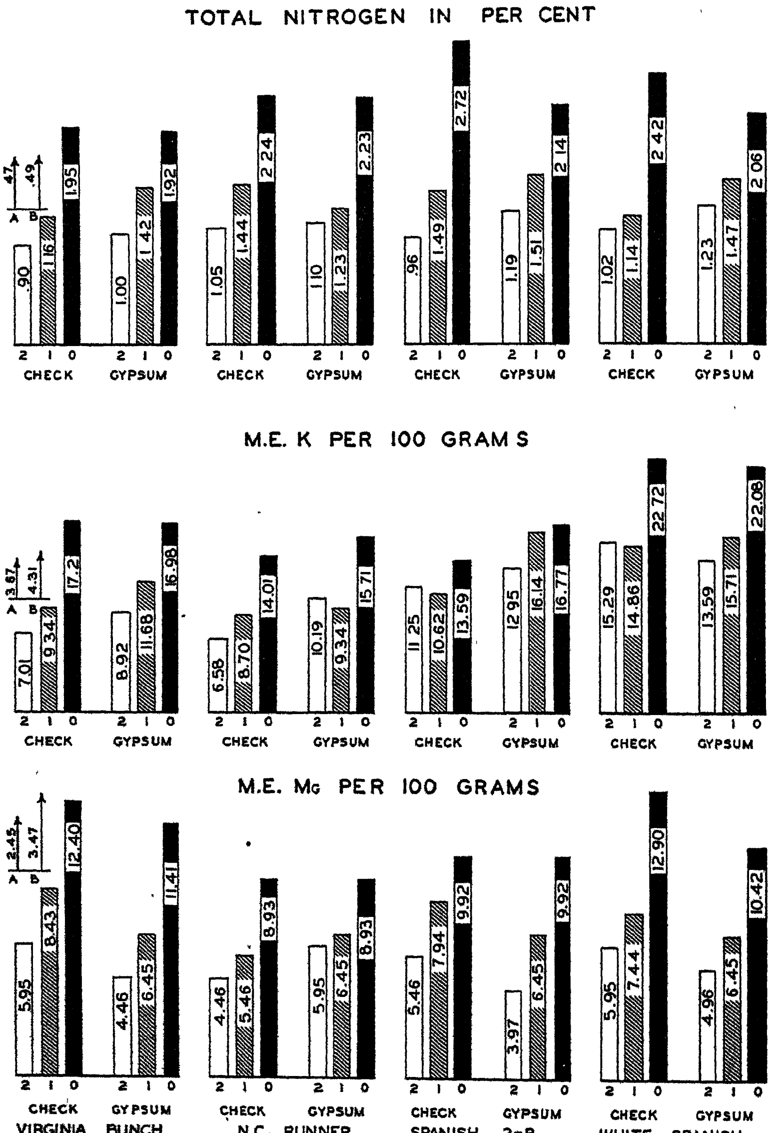

FIG. 3.—The effect of gypsum treatment on the nitrogen, potassium, and magnesium contents of peanut shells of four varieties. 2, 1, 0=number of well-developed kernels per shell. (See Table 1 for treatment description.) A=L.S.D. (.01) for comparing kernel values at a given treatment level; B=L.S.D. (.01) for comparing treatment values at a given kernel level.

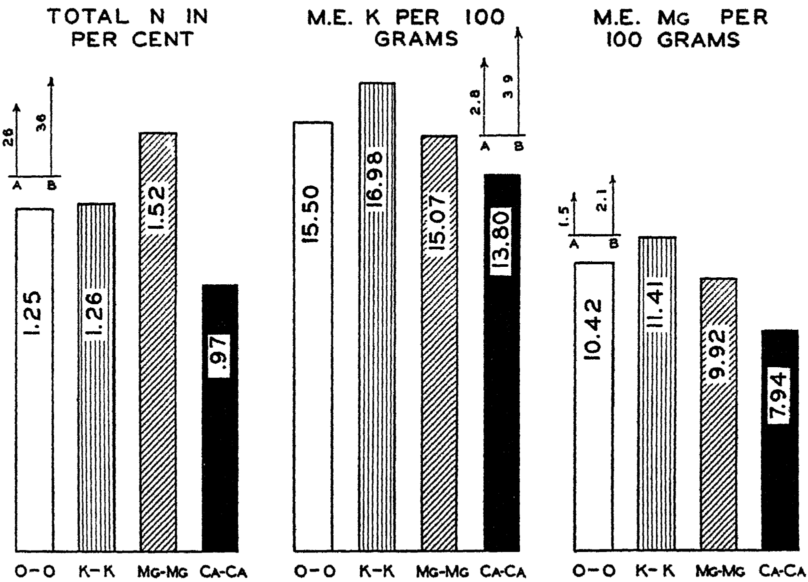

FIG. 4.—The effect of fertilizer treatments on the nitrogen, potassium, and magnesium contents of bulk samples of 2-cavity shells. (See Table 1 for treatment descriptions. Location MLW.) A = L.S.D. (.05); B = L.S.D. (.01).

The most significant feature of the results is the effect of the calcium treatment in lowering the nitrogen, potassium, and magnesium contents of the 2-cavity shells. The potassium and magnesium treatments had little effect on shell composition, although the potassium content was slightly increased by the additions of this element.

When the beneficial effect of calcium on kernel development is considered with the data on the composition of shells in each of the "kernel" groups, the low contents of nitrogen, potassium, and magnesium might be expected. The calcium treatment increased the proportion of well-filled fruit, the shells of which were low in nitrogen, potassium, and magnesium, and consequently lowered the average content of these constituents in the shells.

By the same reasoning, the potassium and magnesium treatments would not be expected to affect appreciably the composition of bulk samples of shells since these treatments had little effect on fruit filling.

The data on the effect of treatments on the three constituents at this location are in agreement with those on bulk shell analyses reported by Collins and Morris (2), as well as unpublished results obtained by Reisenauer.[4] When they are considered along with the data reported earlier in this paper, the necessity of analyzing shells on the basis of the number of well-developed kernels contained is realized.

[4]On file at the North Carolina Agricultural Experiment Station.

CALCIUM CONTENT OF SHELLS AS AFFECTED BY TREATMENT

Calcium analyses of shells of 2-kernel, 1-kernel, and 0-kernel fruit from the experiment at location MLW are presented in Fig. 5. It will be noted that the number of kernels contained in a given shell had no consistent effect upon the calcium content. This behavior is in marked contrast to that noted previously for nitrogen, potassium, and magnesium. Also of interest is the fact the gypsum significantly raised the calcium level in shells of the 2- and 1-kernel groups and resulted in some increase in the calcium content of shells from pops.

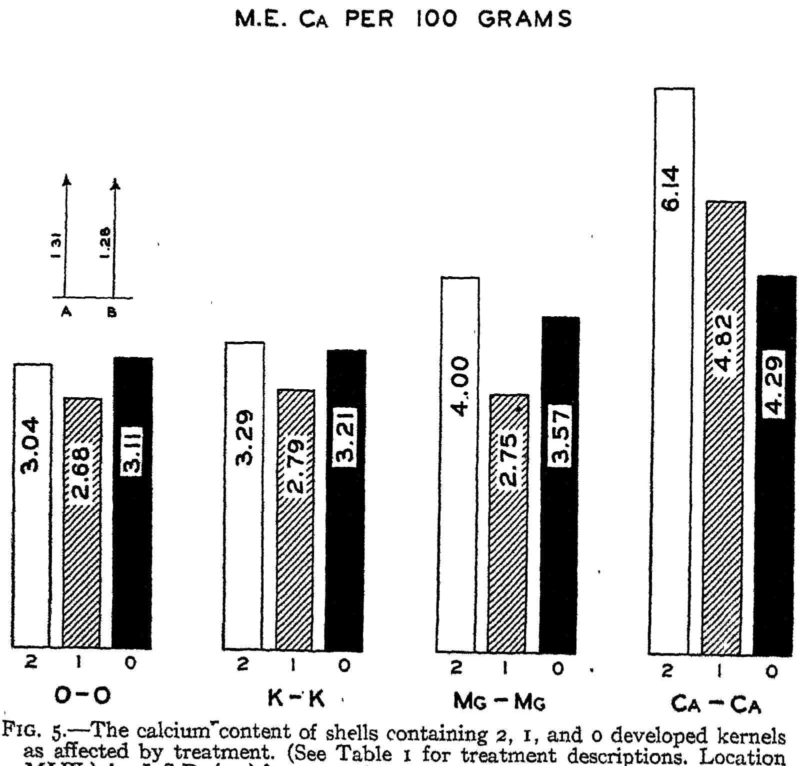

FIG. 5.—The calcium content of shells containing 2, 1, and 0 developed kernels as affected by treatment. (See Table 1 for treatment descriptions. Location MLW.) A = L.S.D. (.01) for comparing kernel values at a given treatment level; B = L.S.D. (.01) for comparing treatment values at a given kernel level.

Data in Fig. 6 show the pronounced effect of the gypsum treatment at the same location in raising the calcium content of a bulk sample of clean 2-cavity size shells wherein all kernel groups were combined. The effect of calcium shown by these data is in agreement with results obtained previously at this station (2), although all values are of a much lower order of magnitude.

Data from locations ENE and WAT, in Table 4, again show the effect of gypsum in increasing the calcium contents of shells of all three categories. Kernel level, however, was without consistent influence.

TABLE 4.—*The effect of treatment and kernel development on the calcium content of shells in two rotation experiments.**

Treatment†	M.E. calcium per 100 grams air-dry tissue							
	Location ENE				Location WAT			
	2 kernels	1 kernel	0 kernel	Average	2 kernels	1 kernel	0 kernel	Average
O	5.00	5.07	5.18	5.08	3.04	3.21	3.68	3.31
G	7.57	7.18	6.04	6.93	4.71	4.50	4.75	4.65
L	4.86	5.04	4.86	4.92	3.39	3.54	4.00	3.64
K	5.00	5.04	4.79	4.94	3.39	4.00	4.89	4.09
L.S.D. (.01)‡	a = 3.14 b = 1.93 c = 0.68				a = 1.29 b = 1.82 c = 1.46			

*Values are averages of three replications.
†See Table 1 for treatment descriptions.
‡a = L.S.D. for comparing values in columns "2", "1", and "0" at a given treatment level; b = L.S.D. for comparing treatment values in a given kernel column; c = L.S.D. for comparing averages.

Similar data for Virginia Bunch, N. C. Runner, Spanish 2B, and White Spanish varieties at the other two locations are presented in Table 5. The Virginia Bunch results were similar to those of the other experiments (Table 4 and Fig. 5), and the same general effects of Calcium treatment were found for the other three varieties. Gypsum resulted in a highly significant increase in the calcium content of shells and there was no consistent effect of the number of kernels developed. In some instances, especially at location FWR, the 0-kernel shells are higher in calcium than the corresponding 2- or 1-kernel shells. This is not generally true at location RPF, however, nor was it true in the other experiments already discussed.

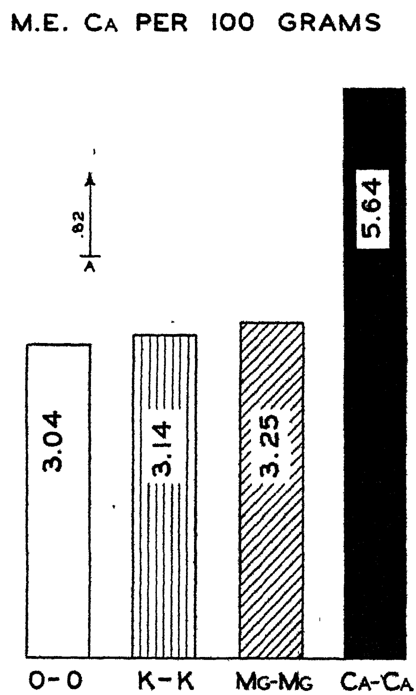

FIG. 6.—The effect of treatment on the calcium contents of bulk samples of 2-cavity shells. (See Table 1 for treatment descriptions. Location MLW.) A = L.S.D. (.01).

INTERPRETATION OF RESULTS

Although it may not be possible at the present time to offer an adequate explanation

TABLE 5.—*The content of calcium in the shells of four varieties as affected by treatment and number of well developed kernels.**

Treatment†	M.E. calcium per 100 grams of air-dry tissue							
	Location RPF				Location FWR			
	2 kernels	1 kernel	0 kernel	Average	2 kernels	1 kernel	0 kernel	Average
				Virginia Bunch				
O	3.36	3.07	3.43	3.29	3.32	3.54	4.29	3.72
G	4.57	4.57	4.14	4.43	5.43	5.14	6.86	5.81
GK	4.75	4.29	4.71	4.58	6.68	5.64	6.82	6.39
LK	4.04	3.50	4.14	3.89	4.14	4.29	4.89	4.44
				N. C. Runner				
O	2.50	2.46	3.50	2.82	2.54	2.68	3.79	3.00
G	3.68	3.64	3.43	3.58	4.39	4.93	6.29	5.20
				Spanish 2B				
O	3.57	3.57	4.82	3.99	3.43	3.64	3.86	3.64
G	4.75	4.57	6.50	5.27	5.39	5.18	7.64	6.07
				White Spanish				
O	4.00	3.86	5.39	4.42	4.79	4.61	5.46	4.95
G	6.39	6.75	6.14	6.43	6.75	8.07	8.29	7.70
L.S.D. (.01)‡	a = 1.70 b = 1.70 c = 1.07				a = 1.96 b = 2.25 c = 1.71			

*Values are averages from duplicate samples each of which was a composite from two replications.

†See Table 1 for treatment descriptions.

‡a = L.S.D. for comparing values in the "2", "1", "0" columns at a given treatment level; b = L.S.D. for comparing treatment values in a given kernel column; c = L.S.D. for comparing averages.

for the observed differences, certain postulations seem logical when the results already discussed are considered together with the effects of treatments on kernel filling. The data presented in Figs. 4 and 6, showing the effect of treatment on the chemical composition of bulk 2-cavity shells, suggest one possible explanation. From these data one might conclude that the addition of calcium directly affects the chemical composition of the shells and that the corresponding increase in fruit filling resulting from this treatment is brought about indirectly through changes in shell composition.

Although such a postulation should receive consideration especially in explaining differences due to treatment, it does not offer a complete explanation for the effect of fruit filling on the chemical composition of shells resulting from a given treatment. An explanation which is believed to be more logical is that the changes in the chemical composition of the shell are brought about indirectly as a result of kernel development. Of importance in considering this explanation are kernel analyses, made on the Virginia Bunch and N. C. Runner varieties at location RPF, which are presented in Table 6. It will be noted that the composition of the kernels is quite constant and that the contents of all constituents listed, ex-

cept calcium, is considerably higher in the kernels than in the shells. (See Tables 3 and 5.) For example, the nitrogen content of kernels is around four times as high as that of the shells, while the magnesium content is twice as high in the kernels.

This observation is of particular importance in offering an explanation for the relationship between nitrogen, potassium, and magnesium contents of shells and fruit filling. When we consider the fact that this large supply of nutrients must enter the developing ovules through the vascular tissue of the shell, it is not surprising that kernel development resulted in a considerable depletion of these three constituents in those shells in which normal kernel development took place. This depletion has occurred in spite of the fact that nutrients are probably moving continuously into the shell from other parts of the plant.

Under conditions whereby abortion took place in both of the two cavities (0-kernel group), the movement of nutrients from the shell into the ovules was probably very slight. When only one of the ovules developed, some removal from the shells of potassium, magnesium, and nitrogen would be expected but not to the extent as when both kernels developed. This accounts for the relatively high level of the three nutrients in the 0-kernel group and the intermediate level in the 1-kernel group.

The importance of calcium in the proper development of ovules has already been referred to. In the experiments reported here, it was the only cation used which resulted in significant increases in ovule development. Yet the chemical analyses of peanut fruits show that the content of this element is very low, especially in the kernels (Table 6). For this reason, one would not expect the calcium content of the shells to be lowered by kernel development to the same extent as was that of nitrogen, potassium, and magnesium.

TABLE 6.—*Contents of three mineral nutrients and nitrogen in the kernels of two varieties at location RPF.**

Variety	Treatment	Nitrogen, %	K, M.E. per 100 grams	Mg, M.E. per 100 grams	Ca, M.E. per 100 grams
N. C. Runner....	Check	4.75	18.51	15.43	1.91
N. C. Runner....	Gypsum	4.91	16.05	15.62	2.07
Va. Bunch.......	Check	5.01	15.07	13.84	1.71
Va. Bunch.......	Gypsum	4.59	15.52	13.24	1.84

*Four replications.

Of interest in considering the role of calcium in kernel formation is the fact that this cation was the only one used which, when added to the soil, was found in increased concentrations in the shells. Also it was the only cation to result in significant increase in fruit filling. These two facts suggest that a high calcium concentration in the shell, through some mechanism as yet unknown, was responsible for proper ovule development and consequent movement of nitrogen, potassium, and magnesium from the shell into the kernel.

Although in the presence of larger amounts of calcium in the shell a higher proportion of ovules develop, it must be remembered that the supply of this element is probably only one of the factors affecting abortion of peanut ovules. This is apparent from a consideration of the relatively low calcium contents of the shells of well-developed fruit from plots receiving no treatment as well as in the high calcium content of shells of unfilled fruit from the calcium-treated plots.

SUMMARY AND CONCLUSIONS

From investigations previously reported it was evident that the failure of kernels to develop properly was at least in part a nutritional problem in which calcium played a vital role.

Chemical analyses of peanut shells were made in an effort to obtain information on the mechanism whereby nutrient supply influences kernel development. Clean shells of 2-cavity size fruit were obtained from plants grown in five field experiments wherein widely different responses to various treatments had been obtained. The shells were divided into three groups, viz., those containing two, one, and zero developed kernels. Each group was analyzed for total nitrogen, potassium, magnesium, and calcium. Shells from four varieties were analyzed at two locations.

Even though marked differences in the effect of treatment on yield and fruit quality had been obtained, there was no effect of treatment on the nitrogen, potassium, and magnesium contents of shells in any given kernel group. The 2-kernel shells, however, were considerably lower in these three constituents than were the 0-kernel shells, while the levels in the 1-kernel group were intermediate. This was found to be true regardless of treatment and was very consistent from location to location.

In the two experiments in which the analyses of the shells of Virginia Bunch, N. C. Runner, Spanish 2B, and White Spanish were compared, the same general effect of kernel filling on composition was noted for all varieties and there was no marked differences in the composition of shells of the different varieties.

In contrast to the results obtained with nitrogen, potassium, and magnesium, the calcium contents of the shells in a given group were markedly increased by the addition of calcium to the soil. There was no definite relationship between the calcium content of shells and kernel development.

Analyses of a bulk sample of clean 2-cavity shells (all kernel groups combined) at one location showed a marked effect of calcium treatment. The nitrogen, potassium, and magnesium contents were decreased and the calcium content was increased by the additions of gypsum. The beneficial effect of calcium in producing a high proportion of 2-kernel fruit was thought to be responsible for these differences.

Kernel analyses were made at one of the experiments and the contents of all constituents except calcium was found to be higher in the kernel than in the shell. It was postulated therefore that the

decrease in the nutrient content of shells of the 2-kernel group was due to the movement of the nutrients from the shells into the developing kernels.

LITERATURE CITED

1. BRADY, N. C., and COLWELL, W. E. Yield and quality of large-seeded type peanuts as affected by potassium and certain combinations of potassium, magnesium, and calcium. Jour. Amer. Soc. Agron., 37:429–442. 1945.
2. COLLINS, E. R., and MORRIS, H. D. Soil fertility studies with peanuts. N. C. Agr. Exp. Sta. Bul. 330. 1941.
3. COLWELL, W. E., and BRADY, N. C. The effect of calcium on yield and quality of large-seeded type peanuts. Jour. Amer. Soc. Agron., 37:413–428. 1945.
4. MIDDLETON, G. K., COLWELL, W. E., BRADY, N. C., and SCHULTZ, E. F., Jr. The behavior of four varieties of peanuts as affected by calcium and potassium variables. Jour. Amer. Soc. Agron., 37:443–457. 1945.

THE DETASSELING HAZARD OF HYBRID SEED CORN PRODUCTION[1]

T. A. KIESSELBACH[2]

EARLY interest in the effects of detasseling corn centered about the possibility of increasing grain yields by diverting food materials used in pollen formation to the developing grain. With the advent of commercial hybrid seed in recent years, detasseled corn to the extent of about one-fourth million acres annually has become a reality and a necessity in the crossing fields of the United States. It is required to bring about specific cross-fertilization in commercial hybrid seed production.

Current interest is focused largely on the direct effects of detasseling practices which unintentionally remove one or more leaves along with the tassel, under crossing-field conditions of ample pollen supply. Two experiments bearing on these questions were completed at the Nebraska Agricultural Experiment Station in 1944, and it is the purpose of this paper to report the results in summarization with those found in the literature. In exceptional cases, the detasseled parent in crossing fields may become heavily infected with smut which gains a foothold at the point of injury where the tassel was amputated. The results from a field of this kind in 1942 are also included. Such data may be of use in appraising the net profits from producing hybrid seed and also in arranging equitable compensation for the contract-production by farmers for seed companies.

An omnipresent additional hazard of detasseling which needs to be reckoned with and guarded against is that of deficient pollen for perfect fertilization. This may result from two causes—drought and failure to synchronize the silking and tasseling of female and male parents. The effect of either upon yield may range up to partial or complete failure. Drought effects are accentuated by placing dependence upon one-third to one-fourth of the plants in a field to provide an ample supply of viable pollen. Losses from this cause are largely prevented by strategic placement of production fields. Since the parental stocks of many hybrids differ in time of flowering, suitable adjustments in time of planting or in differential fertilizer application are the remedies for the second cause of imperfect seedset. Because experimental data are not needed to demonstrate the unfavorable effect of imperfect fertilization of the ears, this hazard of detasseling will not be considered further in this paper.

EXPERIMENTAL PROCEDURE

One test in 1944 was designed solely to determine the effect of removing the tassels before shedding, without loss of leaf. The corn used was Iowa 939 planted by hand in 10-hill rows at a double rate and thinned in the seedling stage to two plants per hill. Alternating rows were detasseled, the entire test consisting of 40

[1]Contribution from the Agronomy Department, Nebraska Agricultural Experiment Station, Lincoln, Nebr. Authorized for publication by the Director as Journal Article No. 372 of the Nebraska Agricultural Experiment Station. Received for publication April 6, 1945.

[2]Agronomist.

replications. The ear corn from each plot was dried moisture-free under forced draft at 100° C and yields per acre figured at 15% moisture content. The stalks also were harvested from the individual plots and acre yields of stover calculated at 15% moisture. The harvesting was done soon after maturity while the leaves were still fairly intact. In order to obtain representative moisture samples, the stalks were run through a small tractor-driven feed chopper, and 1,500-gram samples were taken for drying.

The objectives of the second test in 1944 were to study the effect of removing the tassels both with and without the loss of leaves. The plot technic was the same as described above, except that the corn was U. S. 13 and each of 16 replications consisted of five randomized treatments. These included removal of the tassel together with 0, 1, 2, and 3 leaves, respectively, in comparison with the normal untreated check.

The operation consisted of pulling the tassels by an upward jerk except that, for purpose of better control, many of them were cut off where needed to remove two or three leaves.

RESULTS

REMOVAL OF TASSELS ONLY

The results given in Table 1 are a summary of the 40 replications of the simple comparison in 1944 of plants with tassels versus plants without tassels. Detasseling was accompanied by a 0.4% reduction in grain yield and 1.5% reduced stover yield. It is estimated that this loss of stover approximately equalled the weight of tassels removed and not included with the stalks. Although the number of smutted plants increased from 2.5 to 5.7% as a result of the stalk injury, the smut galls remained small and apparently did little if any injury.

TABLE 1.—*Effect of detasseling without leaf loss on the grain and stover yield of corn (Iowa 939 hybrid), 1944.**

Treatment	Av. number of plots	Stand, %	Smutted plants, %	Moisture, %		Shelling, %	Yield per acre†			
							Grain		Stover	
				Ear corn	Stover		Bu.	%	Lbs.	%
Not detasseled	40	98	2.5	32.5	39.4	83.8	52.7	100	2,371	100
Detasseled . .	40	98	5.7	33.5	38.4	84.0	52.5	99.6	2,336	98.5

*Average of 40 replications in alternating rows of 10 hills each.
†Difference required for significance (5% point): Grain, 1.1 bu.; stover, 196 lbs.

In the other 1944 experiment, Table 2, averages for the 16 replications show a reduction of 2% in yield of grain by removal of the tassels without leaf injury. An unweighted average of both experiments indicates a loss of 1.2% due to detasseling.

DETASSELING ACCOMPANIED BY LOSS OF LEAVES

The comparative effects of detasseling with and without loss of leaves are reported in Table 2. Removal of tassels alone reduced the grain yield 2% compared with the respective reductions of 3.5, 5.9, and 13.6% for the additional pulling of the upper 1, 2, and 3 leaves. The effects of the leaf loss only may be noted by regarding the clean detasseling as the base for comparison. Removal of 1, 2,

TABLE 2.—*Effect of detasseling corn (U. S. 13 hybrid) with and without the loss of leaves, 1944.**

Treatment of tassels	Number leaves removed	Portion of total leaf area removed, %†	Moisture in ear corn, %	Shelling, %	Test weight, lbs.	Yield of grain per acre (15% moisture)‡		
						Bu.	%	%
Untreated	0	0	27.0	86.9	55.0	54.3	100.0	102.1
Detasseled	0	0	26.7	87.5	55.2	53.2	98.0	100.0
Detasseled	1	1.6	26.5	86.7	54.1	52.4	96.5	98.5
Detasseled	2	4.3	25.5	87.3	54.6	51.1	94.1	96.0
Detasseled	3	8.5	26.0	87.3	53.7	46.9	86.4	88.2

*Average of 16 replications of 10-hill rows.
†Leaf areas based on 100 plants.
‡Difference required for significance (5% point): Grain 2.3 bu.

and 3 leaves were responsible, respectively, for losses of 1.5, 4, and 11.8% in yield of grain. Corresponding actual reductions in the total leaf area per plant were 1.6, 4.3, and 8.5%, respectively. It has been noted in other experiments (9)[3] that the upper leaves of plants after the tassel stage are especially efficient by way of photosynthesis, far more than are the lower, older leaves. Removal of all the plant leaves at this stage of development results in near-failure to produce grain. This is to be expected since the plant is dependent upon its leaves for its photosynthetic activities. Such completely defoliated plants yielded 5% in Illinois (3) in 1926; 3% during 4 years in Iowa (4); and 6% during 9 years in Nebraska (9).

A CASE OF EXCESSIVE SMUT FOLLOWING DETASSELING

It is well known that such plant wounds as are caused by wind, hail, and tillage are conducive to increased infection by smut at the points of injury. The extent of infection varies greatly with the season and with susceptibility of the specific hybrid. Likewise, pulling the tassels invites infection when inoculum is prevalent, and one sees occasional crossing fields in which a very high percentage of the detasseled plants are surmounted by a large smut gall. Such a field was located in Dodge County, Nebraska, in 1942, and both the effects of the smut and of its removal were studied as follows:[4]

Sixty-two random groups of three plants each were selected soon after the formation of the "top-smut"[5]—two of the plants with smut and one without. One of the smutted plants in each group had its smut gall removed by cutting off the stalk just below the smut. At maturity the 62 groups, each containing a smut-free plant, a smutty plant, and one with the smut removed (Table 3) were harvested for grain-yield determination.

[3]Figures in parenthesis refer to "Literature Cited", p. 811.

[4]Acknowledgment is made to Owen Rist, formerly Corn Certification Manager of the Nebraska Crop Improvement Association, for cooperation in obtaining these data.

[5]For convenience, the smut formed at the top of detasseled stalks will be designated "top-smut", although it is caused by the common *Ustilago maydis*.

TABLE 3.—*Effect of "top-smut" due to detasseling, upon the grain yield of the ear-parent in a commercial double-crossing field, Dodge County, Nebraska, 1942.**

Condition of plant	No. of plants harvested	Grain yield (15% moisture)		
		Per plant, lbs.	Per acre, bu.	Relative, %
No smut	62	0.445	83.0	100
Smutted	62	0.240	44.8	54
Smut removed	62	0.343	63.9	77

*Data based on 62, three-plant groups containing a plant of each kind. Sixty per cent of the detasseled plants were affected with "top-smut." Seed of hybrid U. S. 13 was being produced in this field, with Wf9 × 38-11 serving as the detasseled parent.

This field had been planted alternately with three rows of the detasseled ear-parent (Wf9 ×38-11) and one row of the tassel-parent (Hy × L317). Sixty per cent of the detasseled plants became naturally smuted, the smut galls ranging in size from that of a baseball to a medium size grapefruit, and yielded only 54% as much grain per plant as did the healthy plants. As a whole, the detasseled plants yielded at the rate of 60.1 bushels per acre. Assuming that there was no unequal competition between the healthy and smutted plants, the yield would have been 83 bushels per acre had all the plants been healthy. Accordingly, an infection of 60% of the plants with "top-smut" due to detasseling caused a loss of 22.9 bushels per acre. Cutting off the tops of the stalks just below the infection increased the grain yield of the smutted plants 43%. Such amputation of the smut galls throughout the field would have reduced the loss from smut to 11.6 bushels per acre.

It would appear from this test that large smut galls draw heavily upon the plant substance during their growth or otherwise unfavorably affect the plant and prevent the normal amount of translocation to the ear. The plants were benefited by early removal of the smut under the prevailing conditions as new galls did not develop. The information is too meagre to indicate how universal would be the benefit from such smut amputation in cases of very heavy infection. Further investigation of this problem would be highly desirable.

In the 10 years of detasseling tests in Nebraska referred to herein, the maximum amount of smut occurring in any year above that in the normal plants, aside from this special 1942 field, was 3.8%. These additional smut galls were too small or too few to affect the yield of grain per acre materially. As judged by the data from mechanically injured corn plants during 9 years of simulated hail studies (9), smut inoculum is distinctly more prevalent earlier in the season than the normal tasseling date in this region.

In a comparative study in Minnesota of the effect of large (over 4 inches diameter), medium, and small (less than 2 inches diameter) smut galls occurring above the ear of F_1 hybrid corn plants, Immer and Christensen (5) found the respective highly significant

reductions in grain yield of 59%, 33%, and 15% for the 2-year period of 1928-29. In a similar study in 1933 with various varieties, hybrids, and inbred lines, Johnson and Christensen (7) found mean ear-corn yield reductions of 86.7%, 33.0%, and 11.6% for large, medium, and small smut galls occurring above the ear.

DISCUSSION AND CONCLUSIONS

A review of the literature pertaining to the effects of detasseling was given by Leonard and Kiesselbach (11) in 1932. The experiments reported by Dungan and Woodworth (3) in 1939 and by Borgeson (1) in 1943 are the only additional papers noted.

The various papers have been somewhat contradictory in their indications, the contradictions arising, perhaps, from differences in detasseling and testing technics and from secondary effects such as development of "top-smut." Some of the papers were published prior to 1900 and their technics are not clearly stated. For example, Ingersol (6) reported a yield reduction of 25% to 35% from detasseling in 1891 and a corresponding loss of 57% in 1892.

Four papers published since 1900 appear to be of primary interest with respect to showing the results from detasseling without loss of leaves. In 1911, Kimbrough (10) reported a loss in grain yield of 1.2% from detasseling. In 1922, an 8-year average increase of 1.6% was reported by Kiesselbach (8). The results were rather variable in that during 3 of the 8 years there was a yield reduction. In 1932, Leonard and Kiesselbach (11) reported an increase of 1.5% which was not statistically significant. In 1938, Dungan and Woodworth (3) obtained an increase of 1.5% and found this to be without statistical significance.

To summarize the standard detasseling experiments of the present century, including those reported herein, each of three publications report a gain of 1.5% and two report a loss of 1.2% from this practice. In an exceptional case of extremely heavy infection with top-smut induced by detasseling in 1942, the yield was reduced 27.6% below what it would have been had all the plants been healthy.

The extensive commercial production of hybrid corn in crossing fields has created a special interest in the effect of pulling one or more upper leaves along with the tassels, as is of frequent occurrence. Three experiments bearing on this question, including the one herein reported, are available. These were conducted by the Illinois (3), Minnesota (1), and Nebraska agricultural experiment stations, and may be summarized as in Table 4.

Although there was some variation in the degree of effect, the trends were the same in all tests. As an average for the three states, loss of one leaf reduced the grain yield 4.3%, two leaves 9.3%, and three leaves 16.4%. Results in Minnesota (1) with hybrids ranging from small and early to relatively large and late, indicate that the effect of pulling a given number of leaves tends to vary inversely with the heritable size and maturity of the hybrid. This no doubt is due to the small early hybrids having fewer leaves per plant and

TABLE 4.—*Summary of the effects of detasseling with and without loss of leaves as reported from Illinois, Minnesota, and Nebraska.*

Treatment of tassels	No. of leaves removed	Grain yield						
		Illinois,* per plant		Minnesota,† per acre		Nebraska,‡ per acre		Av. of 3 states, %
		Lbs.	%	Bu.	%	Bu.	%	
Untreated	0	0.710	98.1	—	—	54.3	102.1	100.1§
Detasseled	0	0.724	100.0	48.7	100.0	53.2	100.0	100.0
Detasseled	1	0.660	91.2	47.5	97.5	52.4	98.5	95.7
Detasseled	2	0.610	84.2	44.7	91.8	51.1	96.0	90.7
Detasseled	3	0.590	81.5	39.5	81.1	46.9	88.2	83.6
Detasseled	4	0.510	70.4	—	—	—	—	—

*Illinois (3), 1938 results.
†Minnesota (1), averages for six hybrids tested in 1941 and 1942 and five hybrids in 1940.
‡Nebraska, 1944 results.
§Two states only.

the leaves removed therefore represent a larger percentage of the total leaf area.

It may be concluded that in commercial detasseling, the field should be gone over so often that tassels need not be pulled before they have emerged so far that leaves do not adhere to them. The saving in yield by careful and efficient operation may offset more than the entire cost of detasseling.

As a general principle, detasseling does not materially affect grain yields unless accompanied by loss of leaves or followed by a heavy infection with smut.

LITERATURE CITED

1. BOREGSON, CARL. Methods of detasseling and yield of hybrid seed corn Jour. Amer. Soc. Agron., 35:919–922. 1943.
2. DUNGAN, G. H. Effect of hail injury on the development of the corn plant. Jour. Amer. Soc. Agron., 20:51–54. 1928.
3. ————, and WOODWORTH, C. M. Loss resulting from pulling leaves with the tassels in detasseling corn. Jour. Amer. Soc. Agron., 31:872–875. 1939.
4. ELDREDGE, J. C. The effects of injury in initiation of hail damage on the development of the corn plant. Iowa Agr. Exp. Sta. Res. Bul. 185. 1935.
5. IMMER, F. R., and CHRISTENSEN, J. J. Further studies on reaction of corn to smut and effect of smut on yield. Phytopath., 21:661–673. 1931.
6. INGERSOLL, C. L. Detasseling corn. Nebr. Agr. Exp. Sta. Bul. 25. 1892.
7. JOHNSON, I. J., and CHRISTENSEN, J. J. Relation between number, size, and location of smut infections to reduction in yield of corn. Phytopath., 25:223–233. 1935.
8. KIESSELBACH, T. A. Corn investigations. Nebr. Agr. Exp. Sta. Res. Bul. 20. 1922.
9. ————, and LYNESS, W. E. Simulated hail injury of corn. Nebr. Agr. Exp. Sta. Bul. 377. 1945.
10. KIMBROUGH, J. M. Corn culture. Ga. Agr. Exp. Sta. Rpt. 1893.
11. LEONARD, W. H., and KIESSELBACH, T. A. The effect of the removal of tassels on the yield of corn. Jour. Amer. Soc. Agron., 24:514–516. 1932.

INVESTIGATIONS WITH THE CASTOR-BEAN PLANT: II. RATE-OF-PLANTING AND DATE-OF-PLANTING TESTS[1]

W. E. DOMINGO AND D. M. CROOKS[2]

THERE was urgent need for information on cultural methods for castor beans in the early years of World War II when the increased demands for drying oils with special qualities focused attention on the desirability of domestic production of this crop. Two of the problems investigated cooperatively by the Bureau of Plant Industry, Soils, and Agricultural Engineering and many state agricultural experiment stations were the rate and date of planting for those varieties which were used in the program. Mimeographed reports[3] of all phases of the cooperative work include yearly data on the rate and date tests and list the cooperating stations and individuals. The 1941 to 1943 results of the 35 rate-of-planting tests in 13 states and the 10 date-of-planting tests in 7 states are summarized herein.

METHODS AND RESULTS

RATE-OF-PLANTING TESTS

The early work on rate of planting has been approached on the basis of a known number of established plants rather than a known amount of seed planted, since the latter would introduce questions of seed viability, depth of planting, emergence, seedling disease, and seed treatment.

The 1941 tests were carried to completion at the following 19 locations: Mesa, Ariz.; Bard, Calif.; Quincy, Fla.; Carbondale, Equality, and Mascoutah, Ill.; Maple Hill and Parsons, Kans.; Beltsville, Md.; Poplarville, Miss.; Arapaho, Chickasha, and Stillwater, Okla.; and Chillicothe, Deport, Lubbock (2 tests), Robstown, and Scottsville, Texas. It is not feasible to present here the detailed data from these tests since, because of the late date at which the program was started, the tests could not be set up uniformly in regard to design, size, and varieties included. It is of interest, however, to note the range of spacings between and within rows that was included among the different tests (Table 1). The number of square feet allowed per plant varied from 1.25 (36 x 5 inches at Bard, Calif.) to 36 (72 x 72 inches at Robstown, Texas). Conclusions which may be drawn from these 19 tests are the generalizations that the castor bean varieties used responded reasonably well to a wide range of spacing and that the number of plants per acre seemed to be more important, within certain limits, than the arrangement or spacing of the plants. The

[1]Contribution from the Division of Drug and Related Plants, Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture, Beltsville, Md. This is the second of a series of papers covering cooperative studies on adaptation, variety comparisons, and cultural methods. Number 1 of the series appeared in this JOURNAL, Vol. 37, pages 750 to 762. Received for publication April 10, 1945.

[2]Agronomist and Principal Horticulturist in Charge, respectively.

[3]D.R.P. 34, 35, and 40 for 1941, 1942, and 1943, respectively.

most satisfactory stand seemed to be approximately 5,000 to 6,000 plants per acre, which represents a spacing of 25 to 30 inches between plants in 42-inch rows.

TABLE 1.—*Spacings included in the 19 rate-of-planting tests in 1941.*

Distance between rows, inches	Distance between plants within the row, inches														
	5	12	18	20	24	25	30	36	38	42	44	48	68	72	96
36	*	*	*		*			*				*			
40			*	*	*		*	*				*			*
42										*			*		
44											*				
48						*			*						*
52		*	*		*		*	*							
72			*		*			*						*	
80		*	*		*			*							

Also: (1) 2 planted rows alternated with 1 blank row†
(2) 2 planted rows alternated with 2 blank rows
(3) 3 planted rows alternated with 3 blank rows
(4) 4 planted rows alternated with 1 blank row

*Indicates occurrence of test.
†It was common practice in the last century not to plant certain rows, thereby leaving space for a wagon during harvest.

In 1942, four uniform rate-of-planting tests were completed, one each in Kansas, Oklahoma, Missouri, and Indiana. Each test was planted with the Conner variety and consisted of four replications of 4 x 20-hill plots with one plant per hill. Different rates of planting were obtained by varying the spacing between plants within 42-inch rows. The distances used were 12, 24, 36, 48, and 60 inches. Only the center two rows of each plot were used for yield data. Planting dates ranged from April 27 at Columbia, Mo., to May 18 at Manhattan, Kans. Data on yield, number of racemes per plant, and plant height are given in Table 2. It will be noted that yields were reduced appreciably by wide spacings, but that yields from 12-, 24-, and 36-inch spacings were about the same. For the 12-, 24-, 36-, 48-, and 60-inch spacings, the numbers of racemes per plant, as an average of the four locations, were 1.43, 2.33, 3.05, 3.55, and 3.93, respectively. When converted to the number of racemes harvested per unit row length, the latter values become 1.71, 1.41, 1.25, 1.12, and 1.00, respectively. Thus the number of racemes harvested per unit row length decreased with the wider spacings, and among spacings which yielded essentially the same (12 to 36 inches) the wider spacings would be preferred on the basis of the number of racemes which need to be harvested by hand for a given yield.

Twelve tests in 1943 compared more critically the three closest rates used in 1942, and more than one variety was included to determine whether the same recommendations should be made for all varieties. These tests were of the split-plot design, in quadruplicate, with varieties in the larger plots and rates in the sub-plots. The ultimate plots were 4 x 10 hills in size and only the center two rows

TABLE 2.—*Data from rate-of-planting tests at four locations in 1942, with the Conner variety in 42 inch rows.**

Spacing within rows, inches	No. of racemes per plant	Plant height, inches	Yield, lbs. of hulled beans per acre
	Manhattan, Kans.		
12	0.9	102	939†
24	1.4	102	869†
36	2.1	105	877†
48	2.4	106	756
60	2.9	101	771
	Stillwater, Okla.		
12	1.2	70	775†
24	1.8	63	759†
36	2.6	67	879†
48	2.9	70	870†
60	3.0	67	782†
	Columbia, Mo.		
12	2.1	—	1,277†
24	3.7	—	1,301†
36	4.6	—	1,215†
48	5.4	—	1,270†
60	6.2	—	1,012
	Lafayette, Ind.		
12	1.5	89	1,036‡
24	2.4	92	949
36	2.9	93	913
48	3.5	91	889
60	3.6	92	745

*Data are means of four replications of approximately 1/100 acre each.
†This mean yield is either the highest at the location or it does not differ significantly (5% level) from the highest yield.
‡Data did not permit statistical analysis.

were used for yield data. In areas where check-planting is common the spacings of 12, 24, and 36 inches between plants were approximated by using 3, 2, and 1 plants per hill, respectively. The yield data from these 12 tests are presented in Table 3. Examination of the data shows that in 6 of the 12 tests the yields from the three rates did not differ significantly. In four of the tests the differences were significant and in favor of the closer spacings. In the remaining two, differences were significant and in favor of the wider spacings; however, one of these (Stillwater, Okla., 12, 24, and 36 inches between plants) deserves special attention because of the significance of the interaction between rates and varieties. Since this indicates that all varieties did not respond alike to the different rates each variety must be considered separately. When this was done, the yield differences (for rates) within Conner and within Kentucky 38 were found to be nonsignificant, whereas those within Doughty 11 were highly significant in favor of the wider spacing. Thus in all cases, except (1) the Stillwater test with Conner in 1, 2, and 3 plants per

TABLE 3.—*Yields in pounds of hulled beans per acre of rate-of-planting tests at 12 locations in 1943, most tests including more than one variety for information on rate × variety interactions.*

Location	Space between rows, inches	Conner, space between plants in row, feet			Doughty 11, space between plants in row, feet			Kentucky 38, space between plants in row, feet			Rate-of-planting averages: Space between plants in row, feet			Least significant difference†		Significance of rates × varieties interaction
		1	2	3	1	2	3	1	2	3	1	2	3	5%	1%	
Lincoln, Nebr.*	42	1,099	1,172	1,011	....	...	....	1,032*	892*	798*	1,066	1,032	905	89	126	No
Manhattan, Kans.	42	1,047	1,055	1,138	622	786	852	1,240	1,160	1,189	930	1,000	1,060	..	...	No
Wichita, Kans.	40	807	655	634	729	679	676	792	581	529	743	638	613	59	81	No
Stillwater, Okla.	42	483	537	507	276	446	444	531	512	477	430	498	476	57	...	Yes‡
Lubbock, Tex.	39	580	609	560	419	506	511	...	...	....	500	558	536	..	...	No
Beltsville, Md.	42	1,380	1,092	1,147	1,219	1,305	972	1,387	1,411	1,028	1,329	1,269	1,049	..	...	No
		Plants per hill, checked			Plants per hill, checked			Plants per hill, checked			Plants per hill, checked					
		3	2	1	3	2	1	3	2	1	3	2	1			
Stillwater, Okla.§	42	397	557	518	....	....	...	..	....	....	397	557	518	78	119	
Woodward, Okla.	42	426	454	514	...	....	....	....	....	....	426	454	514	..	..	
Urbana, Ill.	42	1,650	1,234	1,052	1,412	970	1,027	1,616	1,160	1,223	1,559	1,121	1,101	..	..	No
Robbs, Ill.	42	341	401	366	422	540	446	354	276	331	372	406	381	...	...	No
Lexington, Ky.	42	1,326	1,222	1,349	1,352	1,258	1,301	1,359	1,188	1,100	1,346	1,222	1,250	86	...	No
Princeton, Ky.	42	1,354	1,290	1,156	....	....	....	1,139	1,153	939	1,247	1,222	1,047	143	..	No

*U. S. 4 was grown only at this station. In order to eliminate one column in this table the yields of U. S. 4 at this station are placed under the Kentucky 38 heading.
†Given only where differences were significant.
‡Differences within Conner and Kentucky 38 not significant. Differences between Doughty 1 foot and other Doughty spacings were highly significant.
§36 inch spacing between hills.

hill, and (2) the Doughty 11 variety in the Stillwater test using 1, 2, and 3 feet between plants, the yield differences were either nonsignificant or in favor of the closer spacings.

It will be noted that both of the tests showing significant yield differences in favor of the wider spacings were at Stillwater, Okla. This suggests a rate × station interaction which, if confirmed by additional work, might result in the recommendation of different rates for different areas.

When the data on number of racemes per plant from all 1943 rate tests were averaged, the following values for 12, 24, and 36 inch spacings were obtained: Conner, 1.4, 1.9, and 3.0; Doughty 11, 1.1, 1.8, and 2.7; and Kentucky 38, 2.5, 3.7, and 5.1, respectively. When converted to number of racemes per unit length of row, the values for 12, 24, and 36 inch spacings become Conner, 1.40, 0.97, and 1.00; Doughty 11, 1.22, 1.00, and 1.00; and Kentucky 38, 1.47, 1.10, and 1.00, respectively. These data show that approximately the same number of racemes were harvested per unit row length for the 36 and 24 inch spacings, but this value increased appreciably at the 12 inch spacing. The 1943 data as a whole indicate that with these varieties there is little assurance that spacings of 12 inches or even 24 inches will outyield 36 inch spacings, and that hand harvest would be easier in the 24 and 36 inch spacings because of fewer racemes.

DATE-OF-PLANTING TESTS

Since this species is of tropical or subtropical origin, it seemed that the plant might require a late planting date, yet its habit of continually producing and maturing racemes until frost indicated that to obtain the maximum yield it should be planted at the earliest possible date.

Four uniform date-of-planting tests with the Conner variety were conducted in 1942, one each in Kansas, Oklahoma, Missouri, and Illinois. The Kansas and Illinois plantings were made from mid-April to the last of June, the Missouri plantings were made from mid-April to mid-June, and those in Oklahoma were made from early April to mid-May. The plots, replicated four times, were 4 x 20 hills in size with one plant per hill and only the center two rows used for yield data. Data from the tests are presented in Table 4. At Manhattan, Kansas, the mid-April and early May plantings yielded essentially the same, but both yields were significantly greater than those from all later plantings. At both Urbana, Ill., and Columbia, Mo., the earliest plantings (April 14 and 21, respectively) yielded more than any later planting. At Stillwater, Okla., the first, second, and last plantings (April 1 and 15 and May 15) yielded approximately the same and significantly more than the May 1 planting.

The six 1943 tests were conducted at Manhattan, Kans.; Lexington and Princeton, Ky.; Stillwater, Okla.; Knoxville, Tenn.; and Beeville, Texas. The dates of planting, listed in Table 5, were at approximately 2-week intervals from late March in the Manhattan and Beeville tests to late June in the Lexington and Princeton tests. To determine whether different varieties respond alike to

TABLE 4.—*Data from date-of-planting tests of the Conner variety at four locations in 1942.*

Date of planting	Average No. of racemes per plant	Average plant height, inches	Yields, lbs. of hulled beans per acre
	Manhattan, Kans.		
Apr. 16	3.7	114	1,276*
May 1	3.8	102	1,202*
May 15	2.4	107	938
June 2	1.5	115	564
June 27	1.0	109	321
	Urbana, Ill.		
Apr. 14	2.4	129	1,548*
Apr. 30	1.6	131	1,084
May 19	1.1	137	806
May 29	1.0	132	536
June 15	0.3	123	9
June 29	0.1	112	7
	Columbia, Mo.		
Apr. 21	5.9	—	1,574*
May 5	4.8	—	1,272
May 18	3.6	—	1,150
June 2	4.0	—	895
June 16	3.5	—	604
June 30	2.6	—	344
	Stillwater, Okla.		
Apr. 1	2.7	70	785*
Apr. 15	3.0	71	834*
May 1	2.2	68	703
May 15	2.1	64	798*

*This mean is either the highest at the station or it does not differ significantly (5% level) from the highest yield.

dates of planting, the Conner, Doughty 11, and Kentucky 38 varieties were included in all tests except the one at Beeville where only Doughty 11 was used. Those tests having more than one variety were of the split-plot design with dates of planting in the main plots and varieties in the sub-plots. The sub-plots were 4 x 10 hills in size and in quadruplicate. Only the center two rows of each plot were used for yield data which are presented in Table 5. Except at Stillwater where plots of only two dates were harvested, yield differences were found to be significant at all locations, and the highest yields were obtained from the earliest plantings. At Manhattan the four planting dates from March 30 to May 18 gave similar yields, but differences between each of them and the May 30 yield were highly significant. At Lexington the two April plantings yielded significantly more (1% level) than all later plantings, May plantings yielded significantly more (1% level) than the June plantings, and the difference between the yields of the mid-June and the late-June plantings was highly significant. At Princeton the differences

TABLE 5.—*Yields in pounds of hulled beans per acre of date-of-planting tests at six locations in 1943, most tests including more than one variety for date × variety interactions.*

Date of planting	Variety				Least significant difference		Significance of date × variety interactions
	Conner	Doughty 11	Kentucky 38	Average	5%	1%	
			Manhattan, Kans.				
Mar. 30	1,048	1,070	1,370	1,163*	134	180	No
Apr. 15	1,199	1,143	1,108	1,150*	—	—	
May 1	1,110	1,044	1,159	1,104*	—	—	
May 18	1,205	1,193	1,193	1,197*	—	—	
May 30	762	1,037	974	924	—	—	
			Lexington, Ky.				
Apr. 8	1,528	1,365	1,167	1,353*	128	171	Yes
Apr. 27	1,339	1,383	998	1,240*	—	—	
May 17	1,146	1,098	871	1,038	—	—	
May 29	1,055	1,114	938	1,036	—	—	
June 12	508	630	546	562	—	—	
June 24	0	0	198	66	—	—	
			Princeton, Ky.				
Apr. 29	1,124	1,216	965	1,102*	167	252	No
May 26	856	753	704	771	—	—	
June 23	38	9	96	48	—	—	
			Stillwater, Okla.				
Apr. 1	403	318	308	343	—	—	
Apr. 13	324	308	342	325	—	—	
			Knoxville, Tenn.				
May 1	1,214	1,116	936	1,089*	160	216	No
May 17	835	1,160	861	952*	—	—	
June 1	650	873	733	752	—	—	
June 15	495	454	387	445	—	—	
			Beeville, Texas				
Mar. 25	—	456	—	456*	75	103	No
Apr. 8	—	335	—	335	—	—	
Apr. 22	—	215	—	215	—	—	
May 6	—	237	—	237	—	—	
May 20	—	239	—	239	—	—	
June 3	—	203	—	203	—	—	

*Either this mean yield is the highest at the station or it does not differ significantly (5% level) from the highest one.

between the April yields and those of later dates were highly significant as was the difference between the May and June yields. In the Knoxville test the May plantings produced similar yields but both were significantly greater than the June yields. The earliest planting at Beeville on March 25 yielded significantly more (1% level) than all later plantings. In only the Lexington test did all varieties not respond alike to the different dates of planting. The lack of agreement between varieties in that test was the less abrupt de-

crease in yields of Kentucky 38 from the early to the late dates of planting, as would be expected by its somewhat earlier flowering date.

DISCUSSION

Considering both yield and ease of hand harvest of the present varieties, the optimum spacing between plants in 40 or 42 inch rows (no blank rows) appeared to be 2 or 2½ feet in 1941, and 2 or 3 feet in 1942 and 1943. Since this problem was studied on the basis of the number and spacing of established plants rather than on the actual amount of seed planted, further work will be necessary to determine what rate and depth of planting and what seed treatments are necessary to produce the optimum number and spacing of plants. Until this has been done it will be necessary to estimate seeding rates from known seed weights and observed emergence rates. With seed of medium to good quality it is reasonable to expect that about 50% of the beans planted in a good seedbed will produce established plants. This seems a low percentage of established plants compared to some other crops, but it is substantiated by observations on field plantings. On this basis 10,000 seeds per acre would be required to produce the desired 5,000 plants. The weight of 10,000 seeds will vary from 7 to 10 pounds with the common varieties, depending on the seed size, but roughly 10 pounds of Conner, 8 of Doughty 11, and 7 of Kentucky 38 would be required to plant an acre under favorable conditions. These rates can be obtained easily by proper adjustment of an ordinary corn drill, using extra thick plates to accommodate the larger seed.

The question of rates of planting as they are related to ease of hand harvest deserves further attention in certain areas. Some growers, especially under conditions of limited rainfall, have felt that harvest was easiest in the closest spacings (even though the total number of racemes was greater) since the smaller number of racemes per plant resulted in more uniform maturity of the crop and therefore fewer harvests.

Another factor necessitating further rate-of-planting work is the development of small-stemmed varieties for combine harvesting, where the size and number of racemes are not important factors.

As with many date-of-planting tests it was not practicable in these trials to prepare the seedbed for each planting date as thoroughly as was done for the first one. In general, the seedbeds for all plantings after the first were increasingly compact largely because of rain. The extent to which this and associated factors affect yield has not been determined.

Examination of the two years' data on date of planting reveals that in Tennessee, northern Oklahoma, and points north, yields with these varieties might be reduced materially if planting is delayed until the last half of May or later. Further, within the period before late May there were yield differences in this area in favor of very early planting. Extremely early planting, however, is not recommended because of the difficulty of seedbed preparation, the danger of freezing weather, the slower and possibly less complete

germination, and more seedling disease in colder soil. It seems desirable to plant when the danger of frost is clearly past and the soil begins to warm up, which is earlier in the lighter soils. The optimum planting date in most of the region of adaptation appears to be a few days earlier than the optimum corn-planting time for the particular area.

SUMMARY

Thirty-five rate-of-planting tests and 10 date-of-planting tests were conducted with the castor bean plant from 1941 to 1943 at various locations in the southern half of the United States. This early work on rate-of-planting was done with a known number of established plants rather than a known amount of seed planted since the latter introduced questions of viability, depth of planting, emergence, seedling diseases, and seed treatment. The number of plants per unit area is an important factor in determining yield, but with a given number of plants the present varieties adapt themselves readily to various spacings and arrangements. On the basis of yield and ease of hand harvest (number and size of racemes), the optimum number of plants appears to be about 5,000 per acre, which is roughly one plant each 2½ feet in 40 or 42 inch rows. The spacing within the row can vary between 2 and 3 feet without greatly affecting yield or ease of harvest. Also, similar yields can be expected by using the equivalent number of plants in checked rows. On the basis of field observations with average quality seed of the common varieties in a good seedbed, this number of plants will be produced by seeding approximately 10, 8, and 7 pounds of the Conner, Doughty 11, and Kentucky 38 varieties, respectively, per acre.

Comparison was made of yields from plantings made as early as March 25 (at Beeville, Texas) and as late as June 30 (at Columbia, Missouri). As would be expected with a plant having an indeterminate growth habit, the greatest yields were produced by the earliest plantings. It is not recommended, however, that planting be done extremely early because of the difficulty of seedbed preparation, the danger of freezing weather, and germination problems in cold soil. The optimum planting date in most of the region of adaptation appears to be a few days ahead of corn planting time for the particular area.

BAMBOO FOR CONTROLLING SOIL EROSION[1]

DAVID G. WHITE AND N. F. CHILDERS[2]

BAMBOO has been widely grown for centuries in the Far East but only in recent years has it begun to take its rightful place as an important crop in the Western Hemisphere. In addition to many industrial and construction uses (1, 2, 3, 6),[3] bamboo also is valuable for controlling soil erosion on areas not particularly suited for other economic crops. It grows well on steep hillsides, road embankments, gullies, or on the banks of ponds and streams. The valuable features of bamboo for controlling soil erosion are its extensive fibrous root system, the leafy mulch it may produce on the soil surface, its comparatively dense foliage which protects against beating rains, and its habit of producing new culms from underground rhizomes which allows harvesting without disturbing the soil. Bamboo does not necessarily require the better soil types. In Puerto Rico it grows on soils ranging from heavy hill clays to sandy loams along stream banks. Of course, superior growth is attained on soils which are relatively fertile.

Most of the tropical species of bamboo require a plentiful supply of moisture for vigorous growth; however, they also will tolerate the prolonged periods of dry weather commonly encountered in the Tropics. Bamboo at the Federal Experiment Station at Mayaguez, Puerto Rico, withstood a severe 7-months drought in 1943-44 without damaging effect. Many of the leaves abscissed and growth was slow, but with the advent of the rainy season the clumps again resumed vigorous growth.

MAT OF ROOTS HOLDS SOIL EFFECTIVELY

The soil around bamboo plants is permeated by a mass of intertwining roots, as shown in Fig. 1. The mulch beneath a vigorous 8-year hillside clump of *Bambusa tulda* Roxb. was brushed aside to show this typical development of roots near the soil surface. Roots were found at a distance of more than 17 feet from the clump.

A study was made on the above clump of *Bambusa tulda* to ascertain the distribution of the roots in the soil. Starting at the base of an outermost culm, a ditch was dug to a depth of 4 feet for a distance of 17 feet from the culm. The number of roots exposed in each square foot on the face of one wall of the ditch was recorded. The data are presented in Table 1. Most of the roots, 83%, were present in the upper foot of soil which is the area where roots serve best in controlling soil erosion, Fig. 2. The percentages of roots at lower layers were: 1 to 2 foot depth, 12%; 2 to 3 foot depth, 4%; and 3 to 4 foot depth, 1%. It is evident from Table 1 that the greatest concentration of roots was within 4 feet of the clump. It is interest-

---

[1]Contribution from the Federal Experiment Station, U. S. Dept. of Agriculture, Agricultural Research Administration, Mayaguez, Puerto Rico. Received for publication May 10, 1945.

[2]Plant Physiologist and Assistant Director, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 847.

FIG. 1.—This photograph was taken on the side of a drainage ditch after removal of the mulch. It shows the closely woven mat of bamboo roots which are effective in holding soil under heavy washing conditions.

ing to note a slight increase in the number of roots at a distance 12 to 17 feet from the clump. A drainage ditch for a roadway was encountered near this area. Apparently the moisture supplied by this

TABLE 1.—*The distribution of roots and number exposed per square foot of Bambusa tulda in a heavy clay, Mayaguez, Puerto Rico.*

Distance from clump in feet	Number of roots			
	0–1 foot	1–2 foot	2–3 foot	3–4 foot
0–1	1,300	33	18	0
1–2	1,100	22	14	0
2–3	1,200	44	12	0
3–4	1,020	61	19	6
4–5	485	66	20	0
5–6	390	77	23	6
6–7	231	111	24	7
7–8	154	96	23	8
8–9	134	79	36	10
9–10	94	63	16	7
10–11	85	43	17	6
11–12	85	39	13	8
12–13	116	34	18	18
13–14	102	29	8	15
14–15	204	86	17	23
15–16	215	65	15	8
16–17	187	48	12	10
Totals..........	7,103	996	305	132

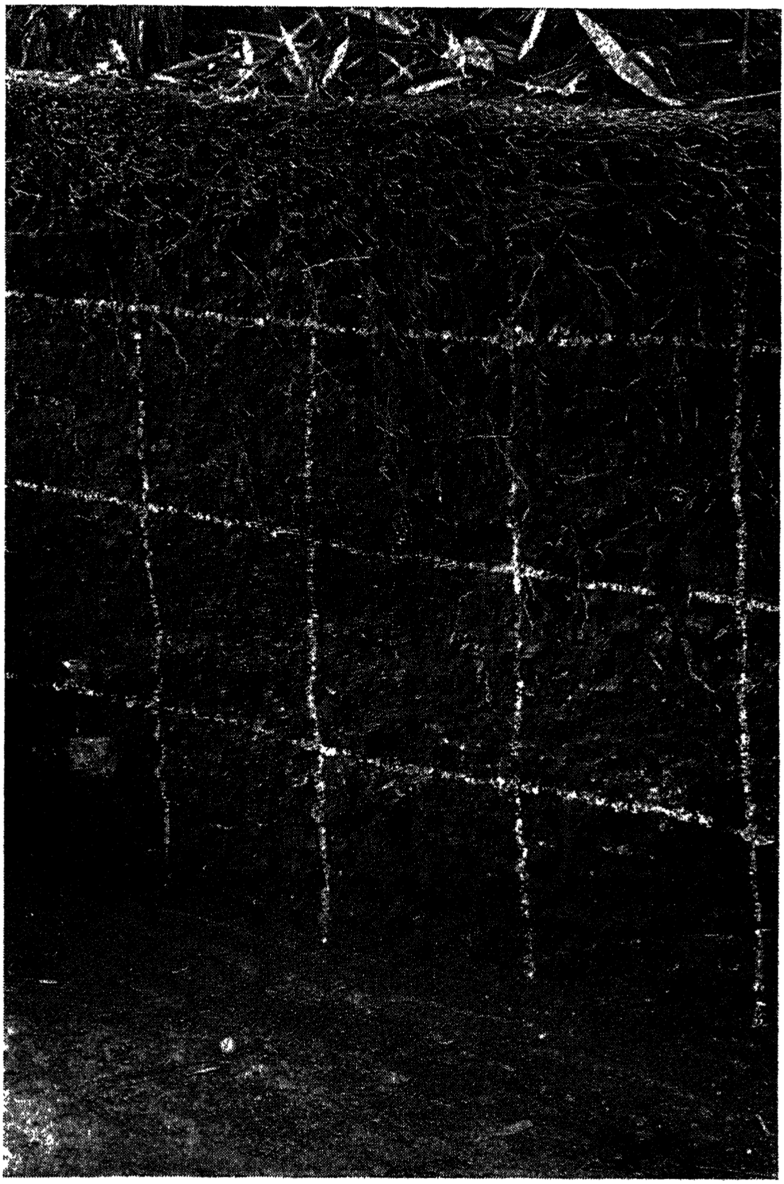

FIG. 2.—Vertical exposure showing that most of the roots of bamboo are located in the upper foot of soil which begins at the base of a clump of *Bambusa tulda* and extends horizontally for a distance of 17 feet. The 1-foot squares are the second, third, and fourth from the base of the clump. The ditch or exposure is 4 feet deep.

ditch caused a slight increase in the numbers of roots at this point. A few roots were seen penetrating the soil to a depth greater than 4 feet.

MULCH ACCUMULATES BENEATH BAMBOO

The leafy mulch which accumulates beneath some species of bamboo collects and conserves moisture in addition to preventing soil erosion. Fig. 3 shows a 2- to 4-inch mulch of bamboo leaves which accumulated during a 3- to 4-month period of dry weather in a 4-year planting of *Bambusa longispiculata* Gamble ex Brandis. The

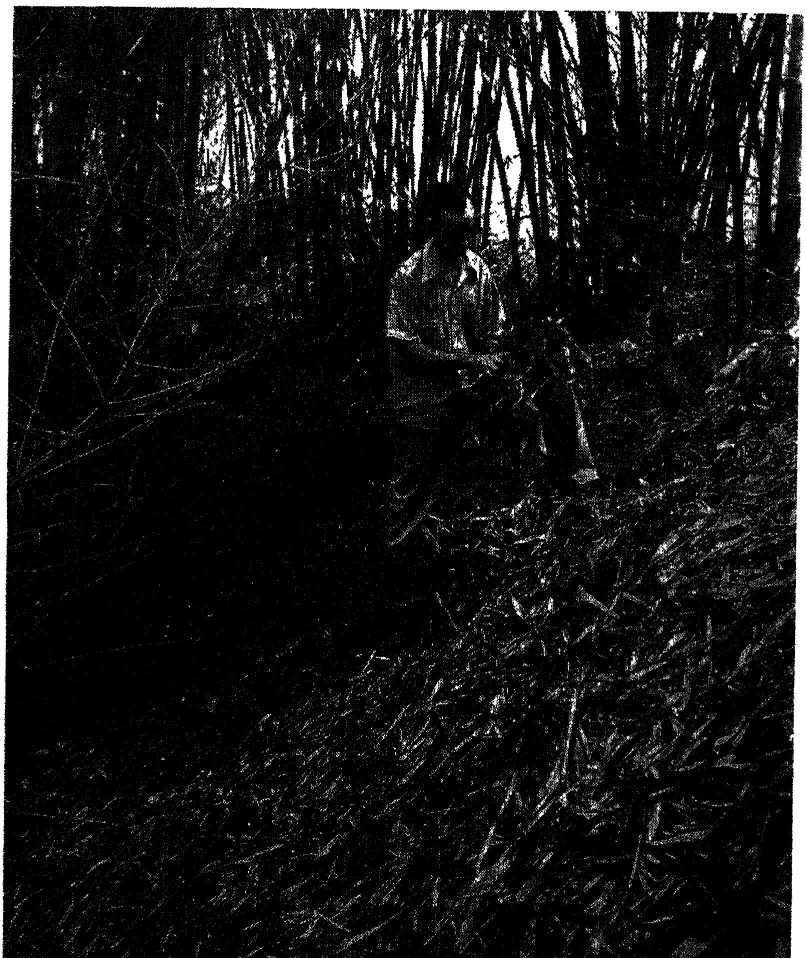

FIG. 3.—During dry periods bamboo sheds many leaves which in this 4-year-old planting of *Bambusa longispiculata* have accumulated to form a 2- to 4-inch mulch. The mulch facilitates the intake and retention of moisture, adds organic matter, and reduces soil erosion. (Same planting as shown in Fig. 4.)

angle of the slope in this planting is 52%—too steep for comfortable walking as seen in Fig. 4. The good stand of bamboo on this hillside emphasizes the feasibility of planting bamboo rather than some cultivated crop which would expose the soil to accelerated erosion. At the time this bamboo was planted several ditches caused by erosion were present, but when the photograph was taken, the ditches were covered with leaves and the soil impregnated with roots. There were no signs of additional erosion.

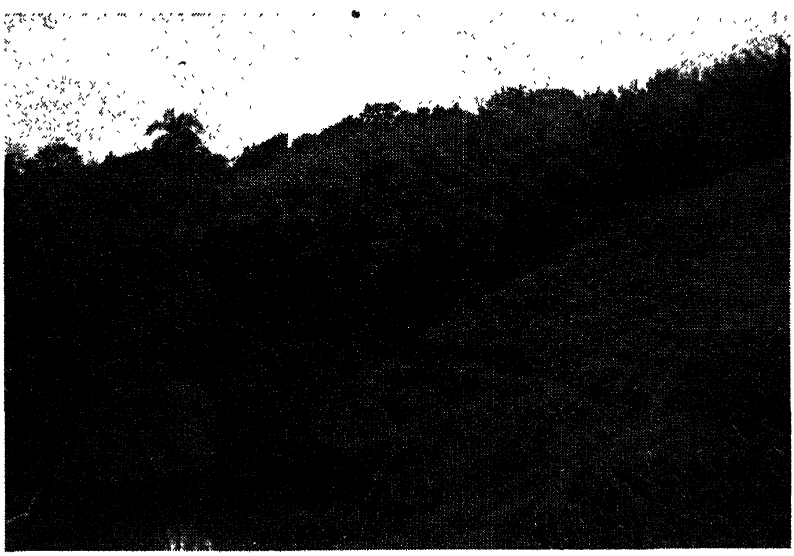

FIG. 4.—This 4-year-old planting of *Bambusa longispiculata*, middle background, at the Federal Experiment Station in Puerto Rico serves to control erosion on a steep hillside in addition to providing culms for industrial purposes.

The ditch shown in the center of Fig. 3 is a culvert outlet from a nearby roadway. A clump of bamboo slightly to the left of the photograph is situated directly in the path of this outlet and serves to disperse the flow of water during rains. The planting was made on the square with the clumps spaced 20 feet apart. Perhaps a better system of planting for steep hillsides is the hexagonal arrangement in which the staggered clumps further retard fast moving water from torrential rains.

BAMBOO FOR ROAD EMBANKMENTS AND ALONG STREAMS

Puerto Rico has many winding roads through the mountainous interior of the Island. Landslides are a problem both above and below the hillside roads. The Department of Interior has used plantings of bamboo with considerable success to maintain fills and steep road embankments (Fig. 5). The bamboo generally used for this purpose is the common species, *Bambusa vulgaris* Schrad. It develops

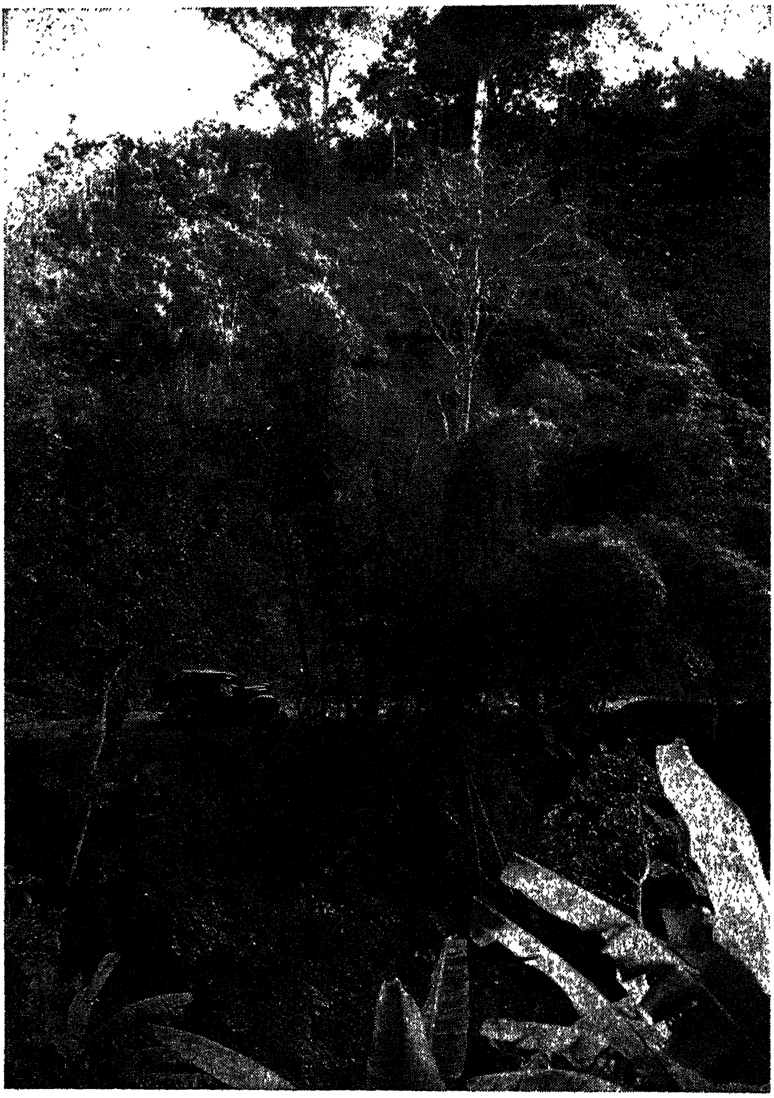

FIG. 5.—Among the hills of Puerto Rico bamboo, mostly *Bambusa vulgaris*, has been used freely by the Department of Interior to stabilize steep road embankments. For this purpose it serves as well or better than any other crop.

large thick clumps, makes a rapid dense growth, and planting material has been readily available. However, many of the species of bamboos introduced by the Federal Experiment Station in recent years will serve equally as well as this common species, and, in addition, will furnish culms valuable for industrial purposes.

Bamboo planted along stream and river banks, as shown in Fig. 6, grows particularly well because of a more even and abundant supply of moisture. The fibrous mass of roots binds the soft banks, and the thick culms arrest strong currents during flood periods. The particular river shown in Fig. 6 frequently goes on a rampage during the rainy season. Before the bamboo was planted large areas of the adjoining experimental field were washed away, especially on the sharp curves. At these critical points a bamboo revetment was constructed (5) as shown in Fig. 7. The soil behind the revet-

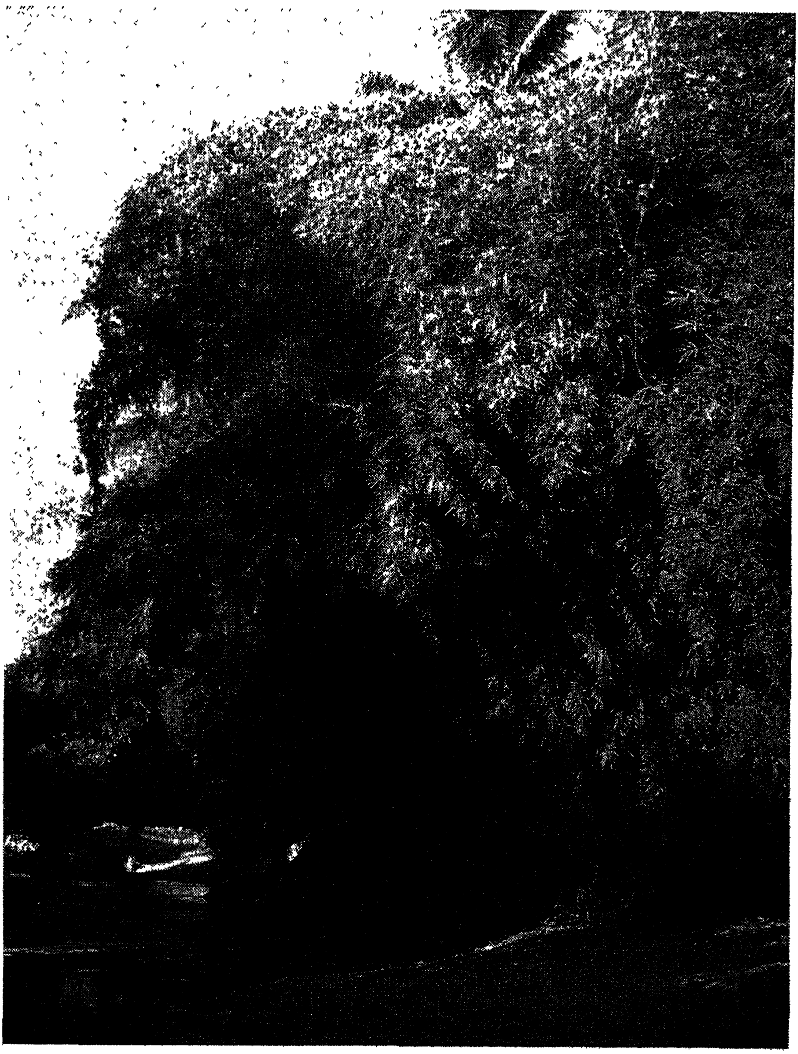

FIG. 6.—Along streams bamboo is effective in preventing the gradual sloughing away of soft banks.

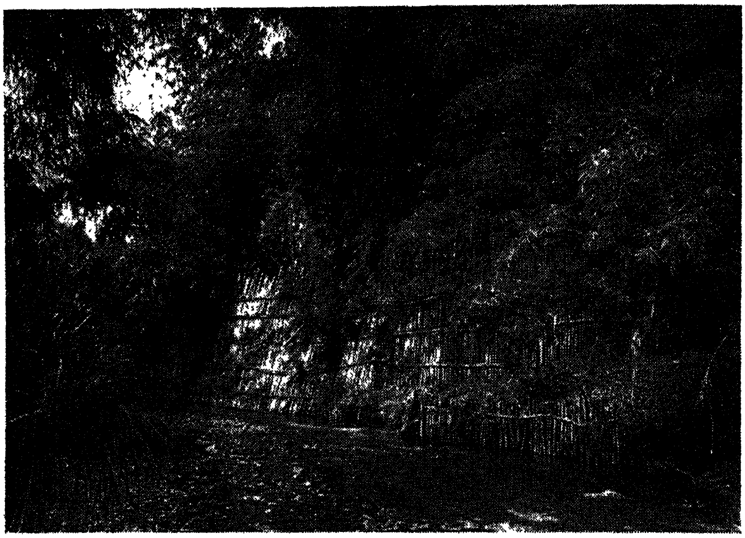

FIG. 7.—On sharp curves of a stream it is possible to use a bamboo revetment; clumps of bamboo behind the revetment provide further reinforcement.

ment is reinforced further by additional plantings of bamboo, thus building a solid wall of living plant material on the banks of the river.

PLANTING SUGGESTIONS

Many species of bamboo will serve in controlling erosion. However, certain species are recommended because there is a marked difference in the industrial value of the various bamboos. Although the powderpost beetle, *Dinoderus minutus* (F.), is a serious pest of cut bamboo, the following introduced commercial species have been found (8, 9) to be relatively resistant to this insect; *Bambusa textilis* McClure, *B. tulda*, *B. longispiculata*, and *B. tuldoides*, Munro. These Oriental species have a system of underground rhizomes which results in the development of more or less confined clumps. On the continent there are temperate species which have a "running" habit of growth and consequently require some attention to prevent them from spreading and eventually becoming a problem.

Bamboo grows best on rich, moist sandy-loam soil, although it can be established satisfactorily on submarginal land not particularly suitable for other crops. Experience at this Station is limited to tropical species which require at least 50 to 70 inches of rainfall distributed throughout the year. These species will tolerate additional rainfall provided the planting is not located where water stands for prolonged periods. In areas definitely low in rainfall the species recommended above should be located on banks of streams or ponds. Bamboo is most successfully established when planted

at the beginning of the rainy season. However, with an evenly distributed annual rainfall, planting can be done at any time. In the continental United States there are several species of bamboo which thrive in the southernmost sections and some succeed as far north as Maryland.

Bamboo is readily propagated by means of mature rooted culm stumps, which average about 20 pounds in weight after being trimmed for planting or shipment. Seed production of many species of bamboo occurs only every 30 to 60 years, after which the parent clump usually dies. Some success has been attained recently with the rooting of side-branch cuttings of certain species (4), but as yet there is a lack of sufficient data for recommendation of this method.

The distance for planting bamboo varies according to the area to be planted and proposed method of utilization. Usually, plantings are made 15 to 25 feet apart, but when erosion control is a major issue and quicker results are desirable, the culm stumps can be planted closer. In Puerto Rico, about 2 years are required to establish a planting, although 4 to 5 years usually pass before good sized, well-matured culms are available for commercial use. It is well to make planting holes at least 1 foot in diameter and 1½ feet deep and to place a spadeful of well-rotted manure or compost mixed with an equal amount of soil in the bottom of each hole. The stump is then planted at the same level as it previously grew. A generous supply of water should be applied immediately after planting, with later applications as needed. Periodic weeding, especially during the first year, assists in better growth of the shoots. A more detailed account of bamboo culture is given by McClure (7).

LITERATURE CITED

1. Anonymous. Bamboo propagation and utilization. Puerto Rico (Mayaguez) Agr. Exp. Sta. Rpt., 1937:26–28. 1938.
2. ———. Bamboo propagation and utilization. Puerto Rico (Mayaguez) Agr. Exp. Sta. Rpt., 1938:50–55. 1939.
3. ———. Bamboo propagation and utilization. Puerto Rico (Mayaguez) Agr. Exp. Sta. Rpt., 1940:33–38. 1941.
4. Cobin, M. Bamboo propagation. Puerto Rico (Mayaguez) Agr. Exp. Sta. Rpt. 1944. (In press.)
5. Horn, C. L., and Arroyo, Armando. New bamboo revetment construction. The Military Engineer. June 1943.
6. Lee, Atherton. Bamboo. Agriculture in the Americas, 4 (7):127–129, 137. 1944.
7. McClure, F. A. Bamboo culture in the Americas. Agriculture in the Americas, 5 (1):3–7; 15–16. 1945.
8. Plank, H. K. Entomology—General Investigations. Puerto Rico (Mayaguez) Agr. Exp. Sta. Rpt., 1943:23. 1944.
9. Plank, H. K. Entomology and Economic Zoology. General Investigations. Puerto Rico (Mayaguez) Agr. Expt. Sta. Rpt. 1944.

LIBERATION OF HCN IN SORGHUM[1]

C. J. FRANZKE AND A. N. HUME[2]

DURING field operations a peculiar odor was detected at a certain location in the sorghum breeding nursery. This odor appeared more evident in the stillness of the early part of the morning than at any other time of day. It was not possible to locate the sorghum strain or strains which might be emitting this odor. The strains at the location where the odor occurred were recorded and seed saved for future tests. These strains were investigated to determine whether growing sorghum plants were capable of liberating HCN.

LITERATURE

A rather extensive review of cyanogensis in plants has been compiled by Leemann (4)[3]; therefore, only some of the literature will be reviewed here.

The form most common in which hydrocyanic acid occurs in plants is in combination as glucosides. These are intermediary compounds formed by the reaction between a sugar and one or more nonsugars. The complex glucosides which contain the HCN-molecule are known as nonliberators, giving off free hydrocyanic gas only when hydrolized by emulsion or by an active animal enzyme or digestive acid. Such action results in the liberation of hydrocyanic acid and forms of sugar and organic acids. Theories reviewed and discussed by Leemann (4) indicate that cyanide is formed in certain plants due to a peculiar type of protein synthesis in which the nitrogen absorbed as nitrates from the soil by the cyanogenetic plants is changed to the form of hydrocyanic acid as an intermediate stage between nitrates and amino-acid in the formation of proteins. In sorghum or sudan grass this protein or glucoside is called dhurrin. Willaman and West (7) contended that the glucoside in grasses was not a storage product. Willaman (6) stated that hydrocyanic acid in sorghum has two forms, a glucosidic as dhurrin and a nonglucosidic. Dowell (1) contends that his experiments did not show the presence of the nonglucosidic hydrocyanic acid.

Hydrocyanic acid does not appear to exist in cyanogenetic plants as free cyanide but is the result of the interaction of an enzyme ("emulsion") and a glucoside which contains CN group capable of being hydrolized to hydrocyanic acid. Finnemore and Gledhill (2) working on four species of Acacia used for fodder in Australia found that all contained a cyanogenetic glucoside. None of them contained an enzyme capable of hydrolizing the glucoside. Stock eating them along with other plants containing the enzyme, or having sufficient hydrochloric acid present in the stomachs, will hydrolize the glucoside and become poisoned.

It is evident that digestive acids, emulsion, or enzymes hydrolize the cyanogenetic glucoside and liberate hydrocyanic acid. Also, the hydrocyanic acid is freed from the glucoside by freezing. Swanson (5) reported that freezing of Sudan grass does not cause a decrease in the cyanide content if the test is made before the plants thaw and wilt. After thawing and wilting the cyanide content dropped rapidly. Franzke, *et al.* (3) tested second growth amber cane during and after a killing frost. They found 12 hours after freezing the second growth, amber cane lost 65% of its original hydrocyanic acid. During the time when the plants were thawing from the frozen condition, they emitted strong hydrocyanic odor.

MATERIAL AND METHODS

The three strains of Dakota Amber sorghum which were recorded in the field for further study under controlled conditions in the greenhouse were strains 1, 19, and 15. Strain 1 is a high-hydrocyanic acid line, having typical leaves and growth habits of Dakota Amber. Strain 19 is a very high-hydrocyanic acid selec-

[1]Journal Paper No. 193 South Dakota Agricultural Experiment Station, Brookings, S. D. Received for publication May 10, 1945.

[2]Assistant Agronomist and Agronomist, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 851.

tion having similar growth habits and maturity to that of strain 1. Strain 15 is likewise a high-hydrocyanic acid selection. The leaves, however, are not typical Dakota Amber leaves. They are broad, thick, and leathery in texture and dark rich green in color. The plants are shorter and more sturdy than those of either strains 1 or 19. The three strains grown under field conditions were observed to be equally free from disease and insect injury.

The sorghum strains were planted in 5-gallon stone jars filled with known amounts of soil from a continuous sorghum plot. Air-dry weights of soil were previously determined to compute the 15% soil moisture level, which was maintained by adding distilled water three times per week. The jars were planted with ample seed of each variety to be thinned later. The plants were thinned in the early seedling stage, leaving 100 seedlings for each variety tested.

The sorghum strains were allowed to grow in the greenhouse until the six-leaf stage before being sealed under bell jars. They were then put on aspirator lines for test. The plants of each strain were examined for growth development before being sealed under the bell jars. Growth was uniform and equal except for strain differences.

A gas-aspirating system equipped with a motor-driven vacuum pump was set up. The air flow from each of the several lateral lines after passing either over the growing sorghum plants or direct was washed through a measured solution of silver nitrate ($AgNO_3$) placed in a Drechsels gas wash bottle, painted black to intercept light. The painted wash bottles containing the known concentrated solution of silver nitrate were placed in a covered container to eliminate further light to prevent disintergration of the solution. At weekly intervals the silver nitrate solutions were titrated by the method described by Franzke, *et al.* (3) and the hydrocyanic acid recorded in milligrams per 100 growing plants.

There were two set-ups or runs made which will be called first and second run, respectively. The first run was started January 10 and completed March 16. The second run was started March 27 and completed May 14. The first run was a preliminary test and was not made in duplicate. The second run was set-up so that all tests were made in duplicate.

The aspirator hook-up was arranged so that there was control of the air flow through each of the lateral lines. In the first run the two lateral lines where the air flow passed directly into the gas wash bottles called checks were designated as lines A and Al. The three air flow lines where the air passed over the sorghum strains were designated as line B for strain 19, line C for strain 15, and line D for strain 1. Also, there was another line where the air flow passed over the soil of a 5-gallon jar without growing sorghum plants designated as line E.

In the second run lines D and E were left out, eliminating strain 1, and also the line where the air flow passed over the soil. The designation of the lines was thus as follows: Line A and Al checks, lines B and Bl strain 19, and lines C and Cl strain 15.

EXPERIMENTAL RESULTS

The first run, as stated, was a preliminary test to determine whether sorghum strains were capable of liberating HCN. The titration of the silver nitrate solution in the receiving flasks of lines A, A1 checks, line B strain 19, line D strain 1, and line E, jar of soil without growing sorghum plants, titrated blank, indicating there was no reduction in the silver nitrate solutions. There was a whitish precipitate formed in the silver nitrate solution in the receiving flask where the air flow passed from line C strain 15. Titration of the solution showed a reduction in the silver nitrate which was due to reaction of HCN liberated by the growing sorghum plants from strain 15. The free hydrocyanic acid liberated reduced the silver nitrate which formed a whitish silver cyanide percipitate. Strain 15 (Fig. 1) shows an increase in the liberation of HCN up to and including the heading stage February 20 after which there was a decrease up to and including the seed formation stage March 12.

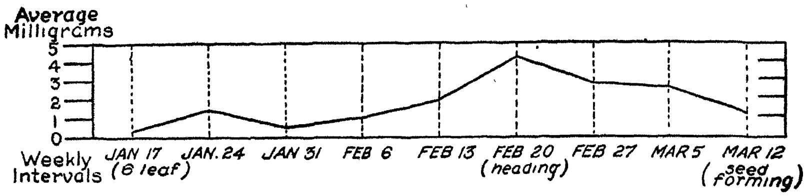

FIG. 1.—Liberation of HCN at weekly intervals in milligrams per 100 plants of strain 15.

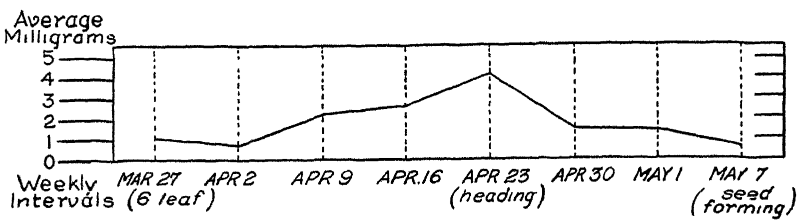

FIG. 2.—Average liberation at weekly intervals of HCN in milligrams per 100 plants of strain 15.

Weekly observations were made on growth and development of the sorghum strains. The growth and development was uniform and fairly normal for sorghum plants grown under bell-jars. March 5 the plants of strain 15 showed yellowing and drying of the lower leaves. March 12 all leaves were practically dead. The lower leaves on strains 19 and 1 began yellowing and drying by March 12 at the seed-forming stage. This premature drying of the sorghum plants was possibly due to lack of sunshine.

On the evening of March 12 the three strains sealed under the bell-jars were disconnected from the aspirator and set outside over night. The morning of March 13 when the plants were found to be in a frozen state, they were reconnected on their respective individual lateral lines and aspirated for a period of approximately 24 hours. The morning of March 14 the silver nitrate solutions were titrated. Strain 1 liberated 18.76 milligrams of HCN and strain 19 liberated 28.68 milligrams of HCN during the 24-hour period. There was no further liberation of HCN from strain 15 which had been frozen when the leaves on the plants were dead.

In the second run the titration of the silver nitrate solution in the receiving flasks of lines A, A1 checks, and lines B, B1 strain 19, titrated blank. Titrating the solution in the receiving flask of lines B and B1 strain 15 revealed a reduction in the silver nitrate solution. The duplicate titrations were similar and therefore they are reported in Fig. 2 as average milligrams of HCN liberated at weekly intervals for strain 15.

Strain 15 tested in the second run showed there was a similar trend in the liberation of HCN (Fig. 2) to that of the first run (Fig. 1). The greatest liberation of HCN was at the heading stage.

Growth and plant development observations were made at weekly intervals. The plants of both strains 19 and 15 by May 1 showed yellowing and drying of the lower leaves. The leaves on the strains at seed formation stage May 7 were all dead and dried. This premature drying of the sorghum plants was possibly due to lack of sunshine, they having been sealed under heavy glass bell-jars. Continued aspiration for 1 week after the plants died resulted in no further liberation of HCN.

A comparison of growth development for the sorghum plants of strain 15 during the first run (Fig. 1) and the second run (Fig. 2) showed slightly more rapid development for the latter due to longer duration of sunlight. This more rapid growth development of the sorghum plants did not greatly affect the average weekly liberation of HCN in strain 15. The average weekly liberation was 1.85 milligrams and 1.80 milligrams of HCN for the first and second runs, respectively.

CONCLUSIONS

1. The investigations show that a selected sorghum strain liberated HCN into the surrounding atmosphere during the process of growth.

2. Selected strains differed in this respect; two strains tested in this investigation which liberated no HCN during growth did so during the process of thawing after being frozen.

3. Sorghum plants that had died and become air-dry no longer liberated HCN.

LITERATURE CITED

1. DOWELL, C. T. Cyanogenesis in *Andropogon* sorghum. Jour. Agr. Res., 16: 175–181. 1919.
2. FINNEMORE, H., and GLEDHILL, W. C. Cyanogenetic glucosides in Acacia. Chem. Abs., 23:4511. 1929.
3. FRANZKE, C. J., PUHR, LEO F., and HUME, A. N. A study of sorghum with reference to the content of HCN. S. D. Agr. Exp. Sta. Tech. Bul. 1. 1939.
4. LEEMANN, A. C. Hydrocyanic acid in grasses. Ond. Jour. Vet. Sci. and An. Ind., 5:97–136. 1935.
5. SWANSON, C. O. Hydrocyanic acid in Sudan grass. Jour. Agr. Res., 22:125–139. 1921.
6. WILLAMAN, J. J. The estimation of hydrocyanic acid and the probable form in which it occurs in *Sorghum vulgare*. Jour. Biol. Chem., 29:25–36. 1917.
7. ———— and WEST, R. M. Notes on the hydrocyanic content in sorghum. Jour. Agr. Res., 4:179. 1915.

METHODS OF EVALUATION OF RED CLOVER STRAINS GROWN ALONE AND WITH TIMOTHY IN SMALL PLOTS[1]

J. H. TORRIE AND J. LEWIS ALLISON[2]

SMALL, replicated row or broadcast nursery plots are used extensively in the preliminary evaluation of red clover strains. Since timothy is commonly sown with red clover, it is important to evaluate strains of red clover in respect to their forage yield when grown in a red clover-timothy mixture. To obtain the forage yield of the red clover portion of such a mixture it is necessary to make a hand separation of all or a portion of the plot, which is a very time-consuming process and thus is not practicable unless the number of strains under test is small. Studies have been conducted at Madison, Wis., since 1937, to determine if the relative forage yields of red clover strains are the same in small plot trials, whether seeded in rows or broadcast and either with or without timothy.

MATERIALS AND METHODS

Trials were made during 1937–38, 1939–40, and 1942–43. A trial was seeded in 1941, but a late spring drought resulted in a very poor stand so it was not completed. The strains of red clover used in the 1937–38 trial were all of the medium red type. Four were locally adapted Wisconsin strains and one was a Minnesota strain. In the 1939–40 trial four medium red strains and one mammoth red strain were used, namely, Commercial (obtained from a local seed company), Composite (a composite of several locally adapted strains), Wilson's White (a white-flowered strain grown in certain areas of Wisconsin for many years), Longhurst (an Idaho strain), and Graham's mammoth (a mammoth type grown by P. S. Graham near Fennimore, Wis., for many years). The same strains were used in the 1942–43 trial with the exception that the certified variety Midland was substituted for the commercial seed lot.

The methods of planting were as follows: Clover in rows spaced a foot apart; clover in rows over-broadcast with timothy; clover broadcast and clover plus timothy broadcast. In the 1937–38 trial the row plots were seeded as a unit separate from and adjacent to the broadcast test. For each group a split-plot design was used in which the strains were assigned at random and planting methods were in strips across the strains in each replicate. For the 1939–40 and 1942–43 tests a split-plot, latin square design was used. Planting methods were assigned at random to the 16 whole plots and the strains to the sub-plots within each whole plot. Four replicates were used in all tests. Each whole plot was 18×20 feet in size and was divided into five sub-plots of equal size.

Seeding was at the rate of 12 pounds of clover when seeded alone and 8 pounds of clover and 4 pounds of timothy in the mixtures, per acre. The plots were harvested when the clover was in the 50% bloom stage. The area harvested for each sub-plot was 4×16 feet. Borders 2 feet in width were used between all whole plots, but no border was removed between sub-plots as it was felt that more error

[1]Contribution No. 200 from the Department of Agronomy, University of Wisconsin, Madison, Wis. Cooperative investigations of the Departments of Agronomy and of Plant Pathology and the Division of Forage Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture. Published with the approval of the Director of the Wisconsin Agricultural Experiment Station. Received for publication May 16, 1945.

[2]Assistant Professor of Agronomy and Assistant Professor of Plant Pathology and Associate Pathologist, Division of Forage Crops and Diseases, respectively.

would be introduced in removing borders, especially in the broadcast plots than would result from competition between strains.

All yields are expressed as tons per acre of dry hay. A 2- to 3-pound sample of green hay was dried to determine the moisture percentage for the forage from each plot. Yields and moisture percentages were determined separately for the component parts of the clover-timothy mixtures. The separation of the clover and timothy was done by hand at harvest. No separation was made for the second crop of the 1939–40 test as the percentage of timothy was negligible. There was no second crop of the 1942–43 test as a severe drought immediately following the first cutting prevented recovery.

EXPERIMENTAL RESULTS AND DISCUSSION

In Table 1 are the given yields of dry matter for the 3 years' results. The analysis of variance of the data in Table 1 is presented in Table 2.

The interaction of strains × methods for the yield of clover, excluding timothy, was not significant for any of the tests. This indicates that the red clover strains tested showed no differential response for yield with the four planting methods. For example, in the 1942-43 tests Wilson's White produced the largest yield, while Longhurst was the lowest for all four methods of planting. The analysis of variance on the combined yield of clover and timothy showed that for the first cut in 1939-40 the interaction of strain × method was not significant, whereas for the first cut in 1942-43 the F values exceeded the 1% level. The reason for the significant interaction in this latter case can best be seen by comparing the yields of Wilson's White and Longhurst. The increase in forage yield of Wilson's White over that of Longhurst for the yield of clover in the plots seeded to both clover and timothy was 0.60 ton for the row plots and 0.76 ton for the broadcast plots, whereas the corresponding differences for the yield of clover + timothy were 0.36 and 0.29 ton, respectively. The difference in yield between the above strains for the plots seeded to clover without timothy was 0.89 ton for the row plots and 0.50 ton for the broadcast plots. The differences in yield of the plots sown with these two strains for the yield of clover excluding timothy in the clover-timothy plots agreed better with the differences found when only clover is sown than does the combined yield of clover and timothy in the clover-timothy plots. This was to be expected since a small yield of clover offers less competition to the timothy than a large yield of clover.

A comparison of the average yields of forage obtained with the four methods shows that the yield produced by clover seeded alone in rows was considerably less than for the other three methods, which differed from each other only slightly.

No significant differences in forage yield were found among strains in the 1937-38 test. The yield of Graham's Mammoth was significantly higher for both cuts in the 1939-40 trial. Wilson's White produced a significantly higher yield than all other strains in in 1942-43, while the yield of Longhurst was significantly lower than that of the other strains. Wilson's White is a vigorous grower, but since a large percentage of the plants possess almost glabrous stems, its yield is reduced, especially in the second cut, in years when leafhoppers are abundant.

TABLE 1.—*Yields of dry matter in tons per acre produced by several strains of red clover grown broadcast or in rows and with and without timothy during 1937–38, 1939–40, and 1942–43 at University Hill Farms, Madison, Wis.*

Strain*	Clover in rows+timothy broadcast			Clover in rows	Clover broadcast+ timothy broadcast			Clover broad-cast	Average		
	Clover	Timothy	Both		Clover	Timothy	Both		Clover	Timothy	Both
1937–38, First Cut											
4 Wisconsin....	0.82	1.50	2.32	2.14	1.21	1.12	2.32	2.38	1.64	1.31	2.29
15 Wisconsin....	0.97	1.44	2.41	2.15	1.44	1.18	2.62	2.38	1.74	1.31	2.39
6 Wisconsin....	0.89	1.64	2.53	2.22	1.24	1.32	2.56	2.21	1.64	1.48	2.38
11 Wisconsin....	1.11	1.42	2.53	2.16	1.25	1.17	2.42	2.24	1.69	1.30	2.34
8 Minnesota....	0.90	1.52	2.42	2.26	1.41	1.11	2.52	2.60	1.79	1.31	2.45
Average........	0.93	1.50	2.43	2.19	1.31	1.18	2.49	2.36	1.70	1.34	2.37
L.S.D. 5%......	0.22	0.26	0.34	0.22	0.29	0.20	0.33	0.29	—	—	—
1937–38, Second Cut											
4 Wisconsin....	0.98	0.40	1.38	1.32	1.32	0.17	1.49	1.72	1.34	0.29	1.48
15 Wisconsin....	0.94	0.42	1.36	1.20	1.17	0.20	1.37	1.46	1.19	0.31	1.35
6 Wisconsin....	1.05	0.39	1.44	1.45	1.16	0.26	1.42	1.63	1.32	0.33	1.49
11 Wisconsin....	1.21	0.42	1.63	1.24	1.21	0.17	1.38	1.68	1.33	0.30	1.48
8 Minnesota....	1.18	0.39	1.57	1.33	1.18	0.16	1.34	1.54	1.31	0.28	1.45
Average........	1.07	0.40	1.47	1.31	1.21	0.19	1.40	1.61	1.30	0.30	1.45
L.S.D. 5%......	0.20	0.06	0.21	0.20	0.22	0.05	0.22	0.22	—	—	—

					1939–40, First Cut						
Wis. Commercial	1.10	0.86	1.96	1.05	0.99	0.75	1.74	1.50	1.16	0.80	1.56
Wis. Composite..	1.19	0.65	1.84	1.19	1.05	0.73	1.78	1.54	1.24	0.69	1.59
Wilson's White..	0.90	0.85	1.75	1.08	0.98	0.75	1.73	1.56	1.13	0.80	1.53
Longhurst......	0.85	0.86	1.71	1.08	0.77	0.85	1.62	1.52	1.05	0.86	1.48
Graham's.......	1.28	0.89	2.17	1.37	1.17	0.89	2.06	2.01	1.46	0.89	1.90
Average........	1.06	0.79	1.85	1.15	0.99	0.79	1.78	1.63	1.21	0.79	1.61
L.S.D. 5%......	0.20	0.21	0.24	0.20	0.20	0.21	0.24	0.20	0.10	0.15	0.12
					1939–40, Second Cut						
Wis. Commercial	0.73	—	—	0.50	0.74	—	—	0.92	0.73	—	—
Wis. Composite..	0.86	—	—	0.60	0.78	—	—	0.91	0.79	—	—
Wilson's White..	0.72	—	—	0.51	0.87	—	—	0.85	0.74	—	—
Longhurst......	0.72	—	—	0.53	0.73	—	—	0.84	0.70	—	—
Graham's.......	0.95	—	—	0.80	0.87	—	—	1.23	0.96	—	—
Average........	0.80	—	—	0.59	0.80	—	—	0.95	0.78	—	—
L.S.D. 5%......	0.14	—	—	0.14	0.14	—	—	0.14	0.07	—	—
					1942–43, First Cut						
Midland........	1.16	0.87	2.03	1.50	1.53	0.30	1.83	1.92	1.53	0.58	1.82
Wis. Composite..	1.20	0.70	1.90	1.54	1.61	0.34	1.95	1.90	1.56	0.52	1.82
Wilson's White..	1.58	0.67	2.25	1.98	1.99	0.32	2.31	2.25	1.95	0.50	2.20
Longhurst......	0.98	0.91	1.89	1.09	1.23	0.79	2.02	1.75	1.26	0.86	1.69
Graham's.......	1.08	0.82	1.90	1.59	1.63	0.43	2.06	2.07	1.59	0.64	1.91
Average........	1.20	0.79	1.99	1.54	1.60	0.43	2.03	1.98	1.58	0.62	1.89
L.S.D. 5%......	0.21	0.20	0.21	0.21	0.21	0.20	0.21	0.21	0.11	0.14	0.11

*All clover strains are of the medium (two-cut) type save Graham's which is a mammoth (one-cut) type.

TABLE 2.—*Analysis of variance of data presented in Table 1.*

Source of variation	D.F.	Mean square, 1937–38			
		First cut		Second cut	
		Rows	Broadcast	Rows	Broadcast
Strains	4	0.003	0.113	0.047	0.050
Error 1	12	0.043	0.090	0.020	0.023
Methods	1	15.475**	10.941**	0.564**	1.624**
Error 2	3	0.023	0.022	0.023	0.100
S × M†	4	0.051	0.028	0.044	0.012
Error 3	12	0.020	0.036	0.017	0.021
Coefficient of variability		9.0%	10.4%	10.9%	10.4%

Source of variation	D.F.	Mean square, 1939–40			Mean square, 1942–43	
		First cut		Second cut, clover	First cut	
		Clover	Clover + timothy		Clover	Clover + timothy
Methods	3	1.644**	1.936**	0.440**	2.047**	1.076**
Error 1	6	0.150	0.055	0.027	0.150	0.101
Strains	4	0.970**	0.354**	0.178**	0.970**	0.581**
S × M	12	0.028	0.029	0.017	0.028	0.061**
Error 2	48	0.021	0.028	0.010	0.021	0.021
Coefficient of variability		11.9%	10.4%	12.6%	9.1%	7.0%

**Highly significant.
†S × M = Interaction of strain × method.

CONCLUSIONS AND SUMMARY

Studies were made during the crop years of 1937-38, 1939-40, and 1942-43 to determine if the relative forage yields of red clover strains are the same in small plot trials whether seeded in rows or broadcast and either with or without timothy.

The interaction of strains × method of planting for the forage yield, excluding timothy, was not significant in any of the trials. This indicates that with small plots red clover strains react the same for forage yield whether seeded in rows or broadcast and either with or without timothy.

The interaction of strains × methods of planting for total yield of forage in the 1942-43 test was significant. The reason was that differences in the yielding ability between strains when timothy was sown are masked by an increased yield of timothy for the low-yielding strains of clover. Thus it is necessary, when a mixture of red clover and timothy is sown, to make a separation of the clover

and timothy in order to evaluate the yield of different red clover strains.

The data indicate that for the range of material tested and under conditions comparable to those found at Madison, Wis., row or broadcast plots seeded to red clover without timothy are satisfactory in testing the yielding capacity of red clover strains in preliminary small plot trials.

NOTES

A DEVICE FOR SETTING FERTILIZER DISTRIBUTORS ACCURATELY AND A SIMPLE METHOD OF CALIBRATION

IT is difficult to adjust most fertilizer distributors to a specific size of aperture to assure delivery of desired rates of fertilizer. When it is necessary to open and close apertures when moving the distributor between replicated plots, it is difficult to maintain a desired rate of distribution of fertilizer. The method of blocking up wheels and turning a given number of revolutions for calibration has been used, but it is a laborious method.

The screw adjustment (Fig. 1) has been helpful in maintaining desired rates of distribution when it is necessary to open and close apertures to stop fertilizer distribution, as well as serving as an accurate adjustment during calibration.

FIG. 1.—Screw attachment placed on fertilizer distributor to facilitate calibration and assure desired size of aperture when it is necessary to open and close aperture during distribution.

A simple and rapid method of calibration has been devised. A metal trough is placed in a position to catch the fertilizer and held secure by two linked chains. The metal trough (ridge-row) is shown in Fig. 2 as attached to the distributor.

The fertilizer rate for an area equal to the width of the distributor and the length equal to the distance covered by ten revolutions of the wheels is calculated. A marker (rag) is tied to the wheel rim and the revolutions are counted. The fertilizer is weighed after each trial and the aperture size is increased or decreased until the desired quantity is obtained. With this simple method it is possible to

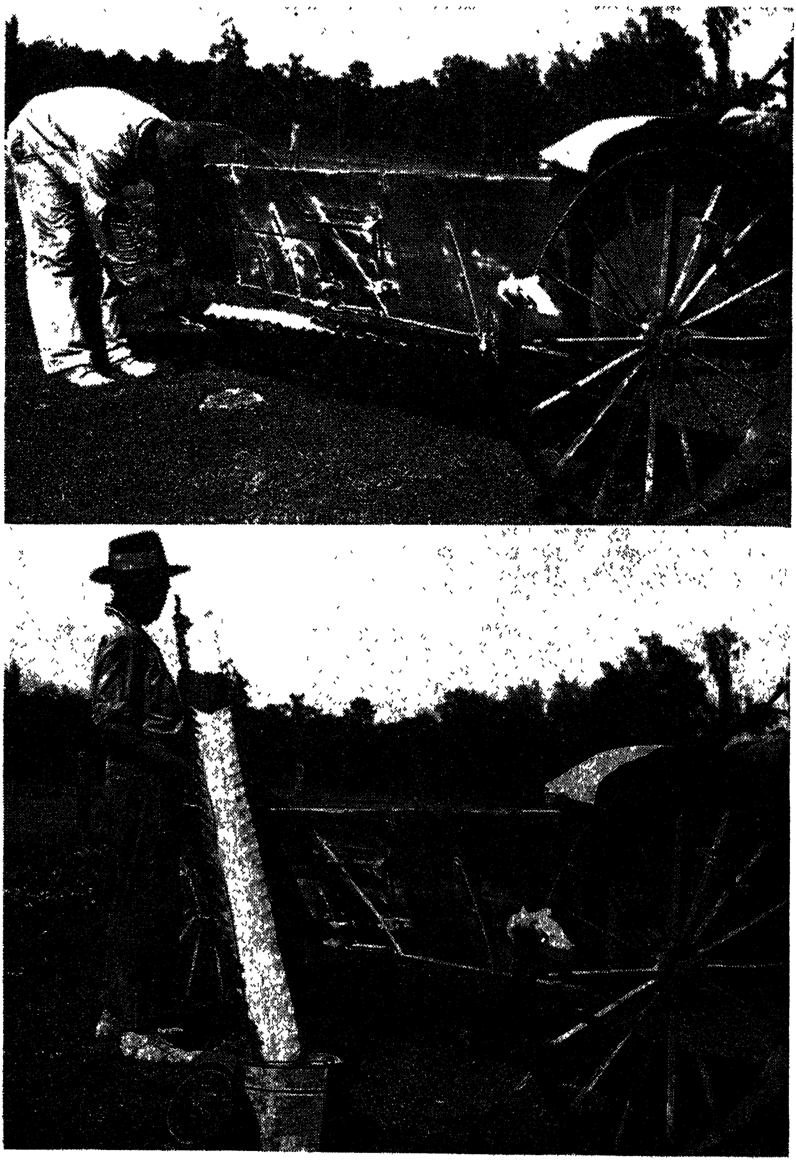

FIG. 2.—Metal trough placed in position to catch fertilizer during calibration is shown above, and the fertilizer is emptied into container for weighing, below.

check distribution rates in the field, and thus, better precision is assured.—R. E. BLASER, *Florida Agricultural Experiment Station, Gainesville, Fla.*

A TROPICAL WINTER PLANT BREEDING STATION ENABLING TWO FIELD GENERATIONS A YEAR

PLANT breeding investigations in cotton require, of necessity, an approach involving considerable time, due to the evident fact that in the temperate climates of the United States but one field crop a year can be produced. In the design of a program of study planned to establish a quantitative basis for the poorly defined character called "quality" in American Upland cottons, *Gossypium hirsutum*, it became apparent that no less than 10 generations would be adequate to accomplish this end. The program called for intervarietal hybridizations to establish widely variant F_2 populations from which selections of new genic combinations could be made. Since the plan required several backcross generations to fix desirable genetic complexes, and since it appeared advisable to self each backcross generation, one can readily see that the time period necessary to achieve this purpose would approach our estimate.

In order to condense this proposed schedule, a new departure from conventional plant breeding procedure was sought. Since each generation should be of sufficient size to lend itself well to a statistical analysis, the use of conventional greenhouse facilities would be inadequate to enable the production of a second generation in any given calendar year. With these considerations in mind, it appeared advisable to secure an environment that would enable the production of a field crop of cotton during the winter months, thereby reducing the time of the experiment to half. The reversal of seasons in the Southern Hemisphere suggested winter culture of cotton in a region of southern latitude comparable to that of our American cotton belt. However, upon investigation of climatological and edaphic data of likely regions in the Southern Hemisphere and tropical zones of the Northern Hemisphere, it appeared advisable to select in the economy of time and money an area meeting the environmental growth requirements for cotton as close to our permanent research station in Dallas, Texas, as possible.

Such a region was located in southern Mexico on the western coastal plain, and two winter crops of experimental cottons have been successfully harvested from this area. This region extends for about 450 miles along the Pacific coast of Mexico, approximately equally distributed north and south of the port city of Acapulco, and is quite narrow, ranging from ½ mile to not more than 4 or 5 miles in breadth. The climate of the area is characterized by hot rainy summers and warm dry winters. A tropical climate prevailing the year around maintains a diverse, though limited, agricultural economy. Corn is the staple cereal and is grown extensively, climatic and soil conditions enabling three crops a year. Citrus fruits, coconuts, and sesame seed are grown for commerce, while truck and home garden crops are harvested in almost every month of the year. Some cotton is grown in the foothills bordering the tropical coastal lowlands; but due to the ravages of insect pests, primarily the boll weevil, cotton production in this area remains limited.

The largest city in the coastal plain is Acapulco in the State of Guerrero. Acapulco is joined with Mexico City by a paved all-weather road and also serves as the terminus for a modern airline which provides two round-trip flights daily to Mexico City. The transportation facilities to Acapulco suggested that region as the most desirable area in the coastal plain for the maintenance of a winter cotton breeding station.

The Department of Agriculture of Mexico maintains an agricultural experiment station 6 miles inland from the coast in the small sheltered valley of the Rio Papagayo in the foothills of the Sierra Madre Occidental. Through the excellent cooperation of Ing. Dario L. Arrieta M., Director General of Agriculture, land was made available for our use at the station. This station is located on latitude 16° 15″ and is approximately 5 meters above sea level. The region is truly *tierra caliente*, located in the tropical zone slightly south of the thermal equator. It has a mean annual temperature of 27° C and average annual extremes of 34.6° and 17.1°.[1] The mean temperature during the winter growing season from September to May is 26.5°. In comparison the Dallas mean annual temperature is 18.6°C, while the mean temperature of the growing season months from April to September is 25.1°. This favorable similarity of temperature date for the Dallas and Acapulco growing seasons confirmed the feasibility of establishing this winter station for our purposes. The western tropical coastal lowlands of Mexico receive considerable rainfall occurring for the most part (90 to 97%) during the months from May to October, the mean annual rainfall at Acapulco over the 8-year recorded period being 1,380 mm. This compares favorably with precipitation data for Dallas, which has a mean annual precipitation of 917 mm, with more than half of the rain falling during the Dallas summer growing season from April to September. The abundance of rainfall during the summer months at Acapulco provides adequate ground moisture without hindering land preparation during September, and at the same time assuring sufficient soil moisture for good germination. The remaining precipitation occurs during the fall months, leaving the fruiting and harvesting months of February, March, and April without any recorded precipitation. Throughout this entire region ground water is abundant during the winter months and is available 5 to 10 meters from the surface, enabling the use of shallow well pumping for irrigation purposes. During the winter growing season the relative humidity remains high, ranging from 79 to 82% for the period September through January, and 77 to 78% during the months of no rainfall of February through April.

Two hectares (2.47 acres each) of clay loam, well drained and located adjacent to an irrigation pipe line leading from a large well, were selected. The major problems in cultivation of a crop following the rainy season lie in weed and insect control. A diversity of native vegetation manifesting luxuriant tropical growth taxes the

[1] WARD, ROBERT DEC., BROOKS, C. F., and CONNOR, A. J. The Climates of North America. Handbuch der Klimatologie. 1936. (Page J 56.)

agricultural diligence of the local farmers. The major and most pernicious of these weeds is the wild morning glory, related to our bindweed. Control of insects, particularly the boll weevil and several hemipterous stainers, was accomplished with frequent dusting of calcium arsenate and sulfur insecticides. There are no pink boll worms reported in the region.

The harvest of the experimental cottons in Dallas was initiated during the latter part of August and was completed by September 15. In the economy of time, ginning, delinting, and ceresan treatment were performed concomitant with the harvest. In anticipation of the need to break seed dormancy, seed were moistened and stored at 5° C previous to transporting them to Acapulco; however, it was found that this procedure was not necessary to insure good germination, and the practice was discontinued. The seed samples were inspected and fumigated by Bureau of Entomology and Plant Quarantine officials at Laredo, Texas, the port of entry into Mexico. They were then transported by automobile to Acapulco and planted early in October. Cultivation, and irrigation when necessary, was taken care of by the local experiment station officials. Flowering usually was initiated by December 15, and by January 1 the plots were ready for the self-pollination operation, which was attended to by our agronomist. The harvest of the winter crop can be accomplished during March, and with the aid of a small laboratory model electrically powered portable gin, the seed was prepared for transporting back to the United States. Ceresan treatment is again required by plant quarantine regulations. The seed entered at the port of Laredo, where they were again inspected and fumigated by quarantine officials. Planting can be initiated early in April at the Dallas station.

The breeding program employing the tropical winter field crop was designed so that all hybridizations (outcrosses and backcrosses) were made in Texas, followed by selfing in Mexico. Selections were made in the subsequent generation which was planted in Texas so that environmental influences might not affect the validity of the selection. The differences of the two environments made themselves evident in plant habit, yield, and fiber characteristics. These data will be published elsewhere. The most apparent difference between the two environments was the photo period. This factor may account for the more sympodial type of growth and the increased yields at Acapulco compared to the growth and yields in Dallas. It was observed that there was a marked difference in the adaptability of individuals and strains of different origins to the differences of environment between the summer and winter stations, but in all cases the results were entirely satisfactory to allow an uninterrupted two-generation-a-year study of all strains and varieties employed in the work.—HAROLD H. WEBBER, *Research Division, National Cotton Council of America, Dallas, Texas.*

NURSERY MARKER AND FURROW-OPENER

SPEED and effectiveness are combined in the tractor-propelled marker and furrow-opener used in our small grain and forage crop nurseries this year. Simply and inexpensively made by S. Stellatella, Research Foreman of the Farm Crops Department, and D. Smith of our Farm Department, the implement has saved much time and drudgery and has resulted in a very neat nursery.

A horizontal iron bar bolted to the cultivator attachment of the

FIG. 1.—Speed and effectiveness are combined in this simple tractor-propelled marker and furrow-opener.

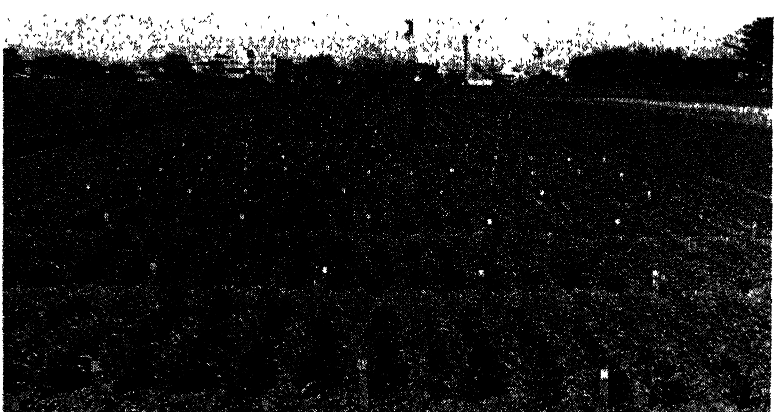

FIG. 2.—Straight rows and even start attest the efficiency of the furrow-opener.

tractor used in the Farm Crops Department carries eight triangular shovels at the ends of short vertical rods. The nursery marker and furrow-opener has its own marking rod that is used to make a guide line for the near front wheel of the tractor on the return.

As rows in the nursery are spaced one foot apart, a 7-foot bar accommodates the eight shovels effectively. Conveniently, this is just right also for making three marks for 42-inch corn rows. A special marking rod is substituted when the marker and furrow-opener is being used for corn.

The depth of the furrow, of course, can be be varied by the lever that actuates the cultivator attachment, and the implement can be raised well up out of the way for turning and for road travel.

Two vertical guides eliminate sway in the cultivator attachment, a sway that obviously would be undesirable in a nursery marker and furrow-opener.

No detailed description of our model is included here since the great merit if the implement is its simplicity and adaptability. Use of the cultivator attachment of a tractor is fundamental and so is the elimination of at least most of the side sway. Naturally modifications will be necessary where other types of tractors are used.

We are pleased with the good performance of the implement in our small grain and forage crop nurseries as well as corn plots. Straight rows and uniform start attest its efficiency.—R. S. SNELL AND S. STELLATELLA, *New Jersey Agricultural Experiment Station, New Brunswick, N. J.*

ERRATUM

REFERENCE is made to the article appearing in Vol. 32, No. 8, Aug. 1940, of this JOURNAL entitled, "The Nitrogen, Organic Carbon, and pH of Some Southeastern Coastal Plain Soils as Influenced by Green-Manure Crops" by Rulon D. Lewis and James H. Hunter.

Renewed interest in the nitrogen and carbon relationships in the soils of the Southeast revealed that the carbon level of soils similar to those studied in the article reported above was much higher than those reported, whereas the nitrogen level corresponded very closely to the previous data. This caused the authors to review the records, and to search out the samples in question from the store room for a re-determination of their carbon content. The new determinations revealed that the carbon content of the soils was exactly twice that reported. The laboratory record books showed that only one-half of the base involved in the intrapment of the carbon dioxide had been accounted for in the calculation of the carbon equivalent for making the calculations of the carbon content of the samples.

All investigators are respectfully requested to multiply the carbon and carbon-nitrogen ratio as reported in the above article by two in order to give the true picture of the carbon and nitrogen relationships. —THE AUTHORS.

AGRONOMIC AFFAIRS

PROCEEDINGS OF NATIONAL JOINT COMMITTEE ON NITROGEN UTILIZATION

THE National Fertilizer Association has assembled the reports of cooperators and subcommittee chairmen of the National Joint Committee on Nitrogen Utilization for 1944 and published them in mimeographed form as the Proceedings of the third annual meeting. While wartime travel restriction prevented a meeting of the Committee in 1944, widespread interest in the Committee's work led to the publication of the Proceedings.

Organizations represented on the Joint Committee, in addition to the American Society of Agronomy, include the American Society for Horticultural Science, the Association of Land-Grant Colleges and Universities, the National Fertilizer Association, the Society of American Foresters, the Tennessee Valley Authority, and the U. S. Dept. of Agriculture. The officers of the Committee include F. W. Parker, general chairman; N. J. Volk, vice chairman; the late H. R. Smalley, general secretary; and the late H. H. Zimmerley, treasurer.

A proposed merger of the National Joint Committee on Fertilizer Application and the National Joint Committee on Nitrogen Utilization was generally approved in a mail vote taken among the members of the latter Committee. Chairman Parker thereupon appointed a committee consisting of N. J. Volk, chairman, W. P. Paden, S. B. Haskell, and J. H. Gourley to confer with a similar committee from the National Joint Committee on Fertilizer Application to work out details of the merger for submission to the membership of the two Committees.

DOCTOR WARBURTON RETIRES

DOCTOR C. W. Warburton, Deputy Governor of the Farm Credit Administration since February, 1940, and from September, 1923, to that date Director of Extension Work in the U. S. Dept. of Agriculture, retired September 30 after 41 years of service.

Prior to 1923, Doctor Warburton was engaged in research with cereals in the Bureau of Plant Industry. He was Secretary of the American Society of Agronomy from 1915 to 1919, President in 1925, and Editor of the JOURNAL for several years.

Doctor Warburton expects to devote much of his time to writing and to extension and farm credit. He will make his home at 4512 Thirtieth Street, N. W., Washington 8, D. C.

BIBLIOGRAPHY ON MINOR ELEMENTS

THE CHILEAN NITRATE EDUCATIONAL BUREAU, INC., announces publication of the sixth supplement to the third edition of the "Bibliography of References to the Literature on the Minor Elements and Their Relation to Plant and Animal Nutrition."

The first edition of this Bibliography was published in August, 1936, the second in November, 1936, and the third, the last complete edition, in February, 1939. Subsequently, the first supplement was

published in April, 1940; the second, April, 1941; the third, May, 1942; the fourth in June, 1943; and the fifth in July, 1944.

The latest publication in this series, the sixth supplement, contains 744 abstracts, which include 97 crops and 53 elements. There are 1,056 authors listed. Complete indices are provided, including an element index, a botanical index, an author index, and an index to abstracts dealing with animal nutrition.

NEWS ITEMS

EUGENE J. CARPENTER, Soil Conservationist in the U. S. Soil Conservation Service, Pacific Coast Region, with headquarters in Portland, Ore., died on September 11, 1945.

—A—

THE WISCONSIN AGRICULTURAL EXPERIMENT STATION has announced the introduction of the "Delwiche Commando" canning pea which has proved practically 100% resistant to the common pea wilt and the near-wilt disease under Wisconsin conditions. The new variety was developed from a cross involving Pride and two pure line selections from Admiral. It is classed as a sweet midseason variety with definitely wrinkled seed. It is double podded and has approximately the same season, although a day or two earlier, as Wisconsin Perfection, and resembles that variety in sieve sizes, vine heights, shape of pod, and yield.

—A—

THE NATIONAL RESEARCH COUNCIL announces that it is now ready to receive nominations and applications for the predoctoral fellowships in the natural, i.e., mathematical, physical, and biological, sciences which it is administering under a grant from the Rockefeller Foundation. These fellowships are intended to assist young men and women, whose graduate study has been prevented or interrupted by the war, to complete their work for the doctorate. It is hoped that these fellowships will do much to accelerate the recovery of the scientific vigor and competence of the country which is so seriously threatened by the loss of almost two graduate school generations of scientifically trained men and women. The annual stipend will be $1200 for single persons and $1800 for married men. In general it is expected that each recipient will spend at least 11 months per year on academic work. An additional allowance up to $500 per year will be made for tuition fees. Fellowships granted to individuals who are eligible for educational support from the "G.I. Bill of Rights" will be at such stipends as to bring the total income from these two sources to that which would be received at the above rates. Prospective candidates for these fellowships are urged to apply at once even though they may be unable to undertake their graduate study in the immediate future. Information concerning these fellowships and nomination-application blanks are being mailed out widely to graduate schools and wartime research laboratories. They may also be obtained by writing directly to the Secretary, Committee on Predoctoral Fellowships, National Research Council, 2101 Constitution Avenue, N. W., Washington 25, D. C.

DOCTOR F. D. KEIM, Chairman, Department of Agronomy, University of Nebraska, has been granted leave of absence to serve on the faculty of the Army University Center at Biarritz, France, where he is Chief of the Agricultural Section and in charge of the Agronomy Division. His address is Dr. F. D. Keim, X008978, Agricultural Branch, Biarritz American University, 6857th O/H Det., APO 772, c/o Postmaster, New York, N. Y.

—A—

LEROY DONALD has been appointed chief agronomist, Sales Agency Department, Barrett Division, Allied Chemical and Dye Corporation. Mr. Donald was formerly southern agronomist for the same corporation.

JOURNAL

OF THE

American Society of Agronomy

VOL. 37 NOVEMBER, 1945 NO. 11

THE COMPARATIVE RATES OF GROWTH OF TETRAPLOID AND DIPLOID SWEETCLOVER, *MELILOTUS ALBA* DESR.[1]

MARSHALL EVANS AND I. J. JOHNSON[2]

MUCH interest has been manifested in the discovery of the action of colchicine as a polyploidizing agent. Polyploids, both autotetraploids and amphidiploids, have been produced in many species by numerous investigators. Many workers have studied artificially induced polyploids primarily from a genetic or cytologic standpoint, while others have described the polyploids with no attempt to measure their economic value. A few investigators have shown that the species under investigation were improved in one or more characters by treatment with colchicine and, oftentimes, by an associated hybridization. Species and sub-species seem to react quite differently to the induction of polyploidy.

Randolph (8, 9)[3] reported that non-inbred autotetraploid corn derived from heterozygous stocks was as vigorous as or more vigorous than the parental diploids. Autotetraploids produced from the diploid inbred lines ordinarily were conspicuously lacking in uniformity and vigor. Hybrids between certain inbred lines exhibited pronounced hybrid vigor. Autotetraploid tomatoes observed by Kostoff and Kendall (7) were taller than diploid plants one month after planting but were surpassed by diploid plants during the following 4 months. Because the autotetraploid plants grew for a longer period of time, they were taller than the diploid plants at the end of the seventh month of growth.

Diploid white clover, a 32-chromosome species, compared by Atwood (1) with induced 64-chromosome sectors, always appeared to have a faster rate of growth than the autotetraploid sectors.

In a study of fruit development in several lines of *Cucurbita* throughout their growth period, Sinnott, Blakeslee, and Franklin (12) found that the relative rate of growth of autotetraploid fruits was considerably faster during the early stages but was no different from the diploid fruits in later development. At maturity, fruit volume was about the same in both types. The cells of tetraploid *Cucurbita* fruits were, on the average, twice as large and half as numerous as the cells of the diploid fruits.

Frankhauser (3) demonstrated that the increase in cell size of the naturally occurring 4n larvae of the Salamander, *Eurycea bislineata*, in comparison with forms of lower chromosome number, was neutralized by a corresponding decrease in cell number.

Gustafson (4) found that the autotetraploid marigold, Guinea Gold, had 58.1% as much growth hormone as the diploid; the autotetraploid of the marigold,

[1]Contribution from the Farm Crops Subsection of the Iowa Agricultural Experiment Station, Ames, Iowa, Journal paper J-1293 Project 152. Received for publication May 26, 1945.

[2]Research Associate and Research Professor of Farm Crops, respectively.

[3]Numbers in parenthesis refer to "Literature Cited", p. 874.

Golden West, had 76.3% as much as the diploid; and the autotetraploid tomato, *Lycoperiscon pimpinellifolium*, had 56.8% as much as the diploid. In this connection it is of interest to note that the leaves, flowers, and seeds of autotetraploid marigolds were larger than those of the diploids.

Sullivan (13), studying polyploid *Lolium perenne* and *Trifolium repens*, found that, in general, an increase in number of chromosomes was frequently associated with an increase in the soluble constituents and moisture content, and with a decrease in the structural constituents.

Randolph (8) indicated that induction of autotetraploidy in corn grain resulted in significant increases in total nitrogen, fats, calcium, potassium, and magnesium with compensating decreases in carbohydrates, sulfur, and phosphorus.

Randolph and Hand (10) analyzed corn and found 2n homozygous yellow corn grain contained 0.0267 ± 0.0004 mg and 4n homozygous yellow corn grain 0.0380 ± 0.0007 mg carotinoid per gram of dry meal.

Kostoff and Axamitnaya (6) reported that the tetraploid tomatoes contained more protein, water, and soluble carbohydrate, and less ash, starch, cellulose, and hemicellulose than the diploids.

Sansome and Zilva (11), using the prophylactic test, determined that all of the autotetraploid strains of tomatoes were approximately twice as active as the diploid when they were examined for their vitamin C content.

The study reported in this paper was made to evaluate the rates of growth of autotetraploid and diploid biennial sweetclover, *Melilotus alba*. To be of commercial value, autotetraploid sweetclover should be at least equal to the common diploid forms in the major agronomic characteristics and superior in some respects to warrant its further recommendation. Observation of greater size of seeds, greater size and vigor of seedlings, thicker and larger leaves, and larger flowers would lead one to believe that the rate of growth and yield of autotetraploid *M. alba* might be superior to that of the diploid form.

MATERIALS AND METHODS

The studies on the relative rates of growth were made in the greenhouse at a temperature of 65° to 75° F during the winter of 1942–43. The soil used in pot cultures was a sterilized mixture of one-third sand and two-thirds field soil. No supplementary nutrients were added to the soil. Natural day length was increased to 16 hours with light from 200-watt clear Mazda bulbs.

Open-pollinated seed of four diploid and four autotetraploid 1-year selfed lines of Iowa Late White sweetclover was planted in 4-inch pots on November 5, 1942. Eight seeds were planted in each of 15 pots per strain to insure an adequate stand for subsequent thinning. The pots were arranged in a completely randomized split-plot design with three replicates. Strains constituted whole plots; five pots of each strain for dates of harvest and measurement constituted sub-plots. After emergence, the stand was thinned to five plants per pot. When the plants had reached a height of approximately 20 cm, the stand was further reduced to two plants per pot. Plants definitely abnormal or diseased were removed between the first and final thinnings.

Beginning November 23, and at intervals until March 8, height measurements were made of two plants in each of the pots in the experiment. Height of a plant was determined in centimeters from the surface of the soil to the maximum height to which the uppermost leaves would extend when gently stroked upward.

On December 21, and at intervals until March 8, all plants in a randomly chosen pot in each of the whole plots were cut at the surface of the soil, weighed, dried at 90° C in an electric oven, and reweighed to determine the percentage of dry matter.

RESULTS

An important part of any study on comparative growth rates is a measurement of the "capital" or original embryo weight of the

material under comparison. This is particularly true for legumes, such as sweetclover, in which the cotyledons function in photosynthesis soon after emergence of the seedling. The seeds of the autotetraploid and diploid strains, therefore, were weighed to serve as a possible explanation of differences in seedling and plant measurements that might have occurred in subsequent stages of development.

These data, given in Table 1, show that each of the four autotetraploid strains exceeded the four diploids in seed weight. The average for the two groups of 2.65 and 1.70 grams per 1000 seeds, respectively, represent an increase of over 50% for the autotetraploid lines. These data are in general agreement with those reported in the literature.

TABLE 1.—*Weight of 1,000 seeds in grams for the four strains of autotetraploid and diploid M. alba used in growth rate studies.*

Autotetraploid strains		Diploid strains	
Strain	Weight in grams per 1,000 seeds	Strain	Weight in grams per 1,000 seeds
101	2.33	102	1.65
103	2.99	106	1.35
105	2.88	111	2.06
109	2.38	116	1.74
Mean	2.65	Mean	1.70

From the time the plants were approximately 1 inch tall until they reached a height of 40 inches, measurements were made at six successive 2-week intervals, and a final measurement 1 month later. The data summarized in Table 2 and presented as a logarithm of height in Fig. 1 show a small difference in height in favor of the autotetraploids for the first six periods after emergence, and a slight advantage for the diploids at the final measurement on March 8. From the analyses of variance summarized in Table 3, the differances between the two groups were significant at the 2-week stage, highly significant at the 4- and 6-week stages, and significant at the 8-week stage of growth. For the last three periods the difference in height between the two groups was not significant. It may be possible that the differences in the early stages of growth were due to the difference in seed weight of the two groups as shown in Table 1.

It should be recognized that the autotetraploid and diploid strains were not derived as seed or sectors from the same plants but were from lines related only as first year selfs of the variety Iowa Late White. Therefore, it must be assumed that the mean growth curves of the four strains of each of the two groups were representative of much larger populations or of much more closely related autotetraploid and diploid lines.

TABLE 2.—*Mean height per plant in centimeters at seven dates of measurement for each of four strains of autotetraploid and diploid M. alba.*

Strain	Plant height in cm on						
	Nov. 23	Dec. 7	Dec. 21	Jan. 4	Jan. 18	Feb. 8	Mar. 8
			4n Group				
101	2.30	3.67	9.07	22.12	35.41	59.67	82.47
103	3.00	4.01	9.59	23.40	38.46	61.79	100.20
105	2.90	3.27	8.94	22.90	35.09	62.59	104.90
109	2.35	3.10	8.44	21.19	38.90	70.64	123.40
Mean	2.64	3.52	9.01	22.38	36.97	63.67	102.74
			2n Group				
102	2.57	2.84	7.48	18.51	32.80	57.16	94.06
106	2.19	2.43	6.76	18.98	31.56	60.19	83.86
111	2.71	3.52	9.57	24.51	42.12	66.81	122.77
116	2.51	2.99	7.47	20.43	35.73	65.08	121.16
Mean	2.50	2.94	7.82	20.61	35.55	62.31	105.34
2n in % of 4n	94.7	83.5	86.8	92.1	96.2	97.9	102.5

Dry weight determinations were begun when the plants were approximately 3 inches tall and continued thereafter at three successive 2-week intervals and, finally, a 1-month interval. These data are summarized in Table 4 and the analyses of variance are found in Table 5. The logarithms of dry weights are presented in Fig. 1. Mean dry weight of autotetraploids was statistically higher at the 1% level only at the first date of harvest, and on subsequent dates the differences were not significant. The mean dry weight of diploid strains gradually approached and finally exceeded the mean weight of the autotetraploid strains at the final date of harvest. It is of interest to note that the log values closely approach a straight line

TABLE 3.—*Mean squares from the analyses of variance for plant height measurements made at seven stages in the growth of autotetraploid and diploid M. alba.*

Source of variation	Degrees of freedom	Mean squares for measurements made on						
		Nov. 23	Dec. 7	Dec. 21	Jan. 4	Jan. 18	Feb. 8	Mar. 8
Strains	7	.2497**	0.7559**	3.4145**	13.447*	3.544**	56.57	868.6
Within 4n	3	.3979**	0.5013**	0.6698	2.720	1.193	69.20	849.8
Within 2n	3	.1450**	0.6088**	4.4452**	22.344**	6.675	58.94	1164.3
4n vs 2n	1	.1191*	1.9338**	8.5562**	18.940*	1.201	11.57	38.2
Replicates	2	.0827*	0.0338	0.0773	0.912	1.722	145.22*	535.5
Exp. error	14	.0171	0.0403	0.3625	3.314	1.195	33.62	398.3

*Exceeds the 5% level of significance.
**Exceeds the 1% level of significance.

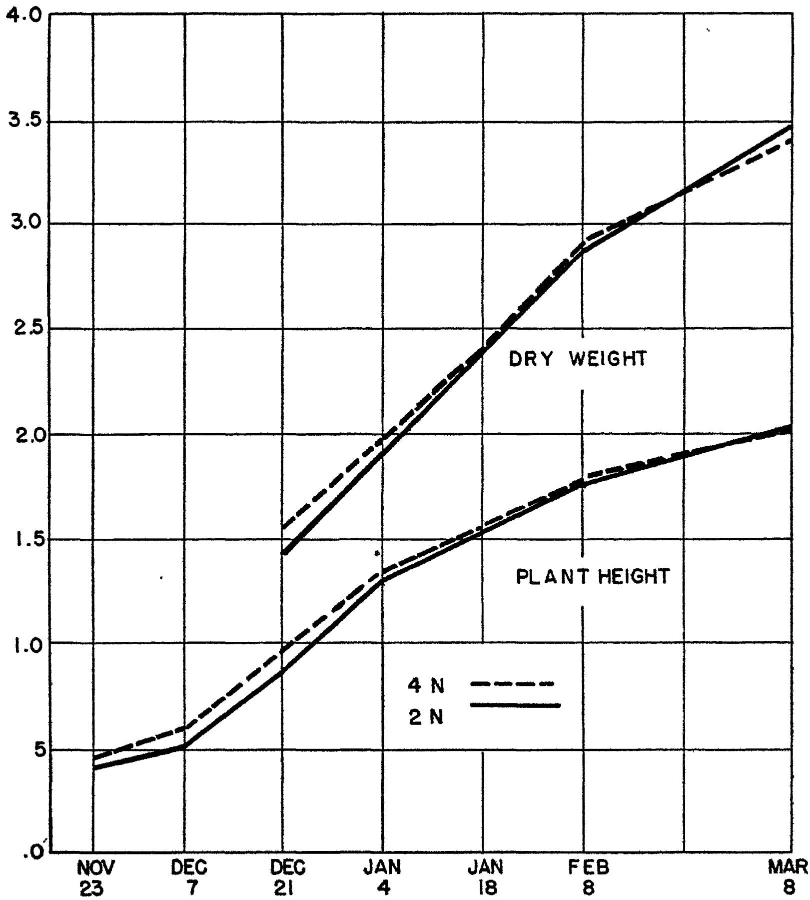

FIG. 1.—Log values of dry weight per plant (upper) and plant height (lower) from 4n and 2n strains of *M. alba* measured at successive stages of plant development.

for dry weight per plant, whereas for plant height there was considerable deviation from period to period.

The dry matter percentage of the two groups of strains is given in Table 6 and the analyses of variance in Table 7. These data show consistently higher values for the diploid group at each of the five stages of growth, and, except for the harvest on January 4, the differences were either significant or highly significant. These results are in agreement with those reported in the literature.

DISCUSSION

From the many investigations reported in the literature and from the results of this study there still remain many questions as yet unanswered on the probable significance of induced autotetraploidy in crop breeding. The larger seeds, leaves, and flowers and the gener-

TABLE 4.—*Mean dry weight per plant in grams at five dates of harvest for each of four strains of autotetraploid and diploid strains of M. alba.*

Strain	Dry weight per plant in grams on				
	Dec. 21	Jan. 4	Jan. 18	Feb. 8	Mar. 8
	4n Group				
101	0.0260	0.0740	0.223	0.720	1.433
103	0.0437	0.1070	0.267	0.733	2.167
105	0.0347	0.0970	0.233	0.717	2.983
109	0.0373	0.0980	0.337	1.053	3.717
Mean........	0.0354	0.0940	0.265	0.815	2.575
	2n Group				
102	0.0280	0.0583	0.247	0.803	2.333
106	0.0247	0.0663	0.187	1.093	1.983
111	0.0317	0.1110	0.320	0.717	3.567
116	0.0257	0.0917	0.240	0.580	3.400
Mean........	0.0275	0.0818	0.248	0.798	2.821
2n in % of 4n .	77.7	87.0	93.6	97.9	109.6

ally more robust appearance of the seedlings would lead one to believe that the autotetraploid sweetclover would be superior to the diploid strains in rate of growth and total yield. The experiment reported here gives evidence of superior size of plants only in the early stages of growth of the autotetraploids. That superiority may be largely due to the greater seed size. Although the differences were not large, increased vigor of seedlings in the autotetraploid sweetclover would be advantageous, especially in regions where difficulty in stand establishment is encountered.

In a preliminary field trial comparing individual F_1 plants from sister diploid and autotetraploid inbred lines of sweetclover (2) no advantage in percentage of leaves, total nitrogen, or coumarin was

TABLE 5.—*Mean squares from the analyses of variance for dry weight made at each of five stages in the growth of autotetraploid and diploid M. alba.*

Source of variation	Degrees of freedom	Mean squares for dry weights on				
		Dec. 21	Jan. 4	Jan. 18	Feb. 8	Mar. 8
Strains.. .	7	.000135**	.001127**	.00739	.09394	2.097
Within 4n.	3	.000161**	.000594	.00787	.07723	2.940
Within 2n.	3	.000029	.001740**	.00903	.14140*	1.831
4n vs 2n...	1	.000376**	.000888	.00100	.00170	0.363
Replicates	2	.000051	.000425	.00185	.05530	2.138
Exp. error	14	.000026	.000219	.00544	.04084	1.372

*Exceeds the 5% level of significance.
**Exceeds the 1% level of significance.

TABLE 6.—*Mean dry percentage at five dates of harvest for each of four strains of autotetraploid and diploid M. alba.*

Strain	Dry matter percentage on				
	Dec. 21	Jan. 4	Jan. 18	Feb. 8	Mar. 8
			4n Group		
101	14.57	13.93	18.67	21.43	27.07
103	14.00	14.73	17.93	22.40	24.43
105	14.23	13.60	18.33	20.37	26.63
109	13.97	14.03	17.47	21.20	24.53
Mean........	14.19	14.08	18.10	21.35	25.67
			2n Group		
102	14.67	15.47	19.43	21.53	27.40
106	15.17	13.57	18.53	21.87	27.27
111	15.37	15.43	20.33	23.80	28.50
116	16.60	15.17	19.47	21.57	28.97
Mean.......	15.45	14.91	19.44	22.19	28.03
2n in % of 4n .	108.9	105.9	107.4	103.9	109.2

evidenced. The plant material used in this preliminary field trial was produced following a method that represents only one of two alternative choices for producing autotetraploid inbred lines, namely, doubling the chromosome number of diploid inbred lines. A second alternative is that of doubling the non-inbred heterozygous stocks followed by inbreeding and establishment of inbred lines. Randolph (8, 9) found the second method to be greatly superior both from the standpoint of increased vigor and fertility. This procedure is now being used in the breeding program but has not progressed sufficiently to utilize the material in crosses.

As yet there has not been a characteristic reported, other than seed and seedling size, which favors the utilization of the autotetraploid form of *M. alba*.

TABLE 7.—*Mean squares from the analyses of variance for percent dry matter at five stages in the growth of autotetraploid and diploid M. alba.*

Source of variation	Degrees of freedom	Mean squares for determinations made				
		Dec. 21	Jan. 4	Jan. 18	Feb. 8	Mar. 8
Strain....	7	2.323*	1.939	2.583	3.014*	8.134**
Between 4n	3	0.230	0.680	0.803	2.100	5.700**
Between 2n	3	2.023*	2.453	1.287	3.517*	2.080*
4n vs 2n...	1	9.500**	4.170	10.810*	4.250*	33.600**
Replicates	2	1.910	2.285	2.965	0.240	1.215
Exp. error.	14	0.576	0.939	1.580	0.861	0.496

*Exceeds the 5% level of significance.
**Exceeds the 1% level of significance.

Since natural autotetraploids, such as orchard grass, crested wheatgrass, tall oatgrass, and birdsfoot trefoil, do exist in nature, it is only reasonable to assume that in these species there has been an evolutionary advantage from chromosome doubling. However, natural selection has taken place within a very large population over many years. Plant breeders may utilize only a small population in a relatively short time in producing and selecting autopolyploid species equal in agronomic characteristics to those that occur naturally. It is of significance to note that in the naturally occurring autotetraploid species the haploid chromosome numbers are low (seven for the grasses and six for birdsfoot trefoil) and that seed production is not now impaired. If induced tetraploidy is to be of value, it would seem that the crops most likely to be successfully used would be those, like sweetclover, that have a comparatively low chromosome number. Production of superior horticultural crops presents a somewhat different possibility for the utilization of induced autopolyploidy in that certain of these crops may be maintained by asexual propagation.

A low degree of self-fertility in autotetraploid sweetclover has been reported by Johnson and Sass (5) and by Evans (2). A large number of individual plants representing first and second generation inbreds, F_1 crosses, F_2 generations from several crosses, and backcrosses are in process of further inbreeding and selection particularly in respect to self-fertility. Final decision on the possibilities of utilizing autotetraploid sweetclover probably should be deferred until inbred lines established from these sources have been more fully investigated.

SUMMARY

A greenhouse study was conducted to compare diploid and colchicine-induced autotetraploid sweetclover, *Melilotus alba*, in relative rates of growth.

The replicated study from open-pollinated seed of four unrelated 1-year selfed lines of each of two groups, autotetraploid and diploid sweetclover, indicated a significantly greater vigor of autotetraploid plants in early stages of growth but indicated a trend toward equalized height and weight at later dates of determination. Differences in weight of seedlings were attributed to larger seed size of the autotetraploid strains. A slightly lower percentage of moisture was detected in diploid plants.

It is suggested that autotetraploid lines should be produced by doubling the chromosome number of non-inbred plants to permit selection for desired characters during the progress of inbreeding.

LITERATURE CITED

1. Atwood, Sanford S. Colchicine-induced polyploids in white clover. Jour. Amer. Soc. Agron., 36:173–174. 1944.
2. Evans, Marshall. The comparative agronomic value of tetraploid and diploid sweet clover, *Melilotus alba* Desr. Unpublished Thesis. Library, Iowa State College, Ames, Iowa. 1944.
3. Frankhauser, G. Polyploidy in the salamander, *Eurycea bislineata*. Jour. Hered., 30:379–388. 1939.

4. GUSTAFSON, F. G. Growth hormone studies of some diploid and autotetraploid plants. Jour. Hered., 35:269–272. 1944.
5. JOHNSON, I. J., and SASS, J. E. The production of tetraploid forms of *Melilotus alba* by colchicine treatment. Jour. Amer. Soc. Agron., 36:214–227. 1944.
6. KOSTOFF, D., and AXAMITNAYA, I. A. Studies on polyploid plants. IX. Chemical analyses of diploid and their autotetraploid plants. Compt. Rend. Acad. Sci. U.R.S.S., 2:295–297. 1935. (Original not seen; cited in Sullivan, J. T. Further comparisons of plants with different chromosome numbers in respect to chemical composition. Jour. Amer. Soc. Agron., 36:537–543. 1944.)
7. KOSTOFF, DONTCHO, and KENDALL, JAMES. Studies on polyploid plants. Gartenbauwissenschaft, 9:20–44. 1935.
8. RANDOLPH, L. F. An evaluation of induced polyploidy as a method of breeding crop plants. Amer. Nat., 75:347–362. 1941.
9. ————. The influence of heterozygosis on fertility and vigor in autotetraploid maize. Genetics, 27:163. 1942.
10. ———— and HAND, DAVID B. Increase in vitamin A activity of corn caused by doubling the number of chromosomes. Science, 87:442–443. 1938.
11. SANSOME, F. W., and ZILVA, S. S. Polyploidy and vitamin C. Biochem. Jour., 27:1935–1941. 1943.
12. SINNOTT, E. W., BLAKESLEE, A. F., and FRANKLIN, ALICELIA. A comparative study of fruit development in diploid and tetraploid Cucurbits. Genetics, 26: 168–169. 1941.
13. SULLIVAN, J. T. Further comparisons of plants with different chromosome numbers in respect to chemical composition. Amer. Soc. Agron., 36:537–543. 1944.

SOME CONDITIONS AND INFLUENCES PERTAINING TO THE NATIVE FORAGE CROP OF THE NORTHERN MIXED PRAIRIE[1]

B. W. ALLRED[2]

THE importance of livestock production in the United States at present assumes the deepest significance of historic time. There is on hand the largest number of grazing animals of all time to be managed and fed. The extraordinary demand for livestock products at home and abroad necessitates the greatest efficiency in animal production and management of grazing resources.

A large segment of livestock products must come from native grazing lands. Maintaining those grazing lands already in vigorous condition and improving poorer ones is a vital task. It is highly essential for maximum production and for maintaining and efficiently using soil resources.

Fortunately the northern mixed prairie[3] is generally in the best condition for heavy livestock production than it has been for many years. These ranges have made an almost miraculous recovery since the drought of the thirties. Much credit for this should be given to stockmen who have carried forward a diligent program of improvement, taking advantage of opportunities to increase water developments for livestock, to reseed many abandoned farm lands to grass, and to rest overused and drought-damaged grazing areas. Most of the grasslands have been greatly favored by improved climatic conditions which, combined with general livestock shortages until about 1939, have vastly helped improve the forage conditions throughout. However, much remains to be done on numerous areas where too close grazing has delayed recovery.

Livestock improvement has generally gone ahead of grassland improvement. However, if efficiency is to be obtained from well-bred range livestock, they must be provided with adequate nutritious forage. Grass is the basic material that livestock harvests and manufactures into needed animal products essential to war and peacetime purposes. Therefore, knowledge of native grazing plants and forage conditions is vital to the successful management of basic grazing resources. Individual native grazing plants whether grasses, shrubs, or nongrassy herbs have distinctive growth habits and feeding values as do small grains, corn, alfalfa, and timothy. Sound management of the native forage crop, which consists of many species, is rendered more difficult than that of a single farm crop, like corn or alfalfa. The better native grazing grounds are usually covered with mixtures of grasses, sedges, nongrassy herbs, and sometimes browse plants as

[1]Contribution from the Northern Great Plains Region, Soil Conservation Service, Lincoln, Nebr. Received for publication May 28, 1945.

[2]Regional Chief of Operations.

[3]For the purpose of this discussion, the northern mixed prairie is considered as being that area which lies between Canada on the north and Kansas and Colorado on the south, and between the Rocky Mountains on the west and the 98th meridian on the east. The discussion covers neither the grazing lands of the Nebraska Sandhills nor South Central Nebraska.

well, which may grow at different seasons of the year and may have different values for grazing and soil protection.

EFFECT OF PAST CLIMATES AND PLANT CLIMAXES ON PRESENT MIXED PRAIRIE

Present-day grasses are probably the lineal descendants of some primitive fescue which evolved from sedge-like ancestors in the Cretaceous geologic period. Grasses and other vegetation have been modified throughout the ages as environment has been changed by shifting climates.

The mixed prairie grassland association dominates in over 75% of the area. The controlling life form is grassland (5).[4] It is composed of climax, midgrasses, short grasses, and dryland sedges (Fig. 1), plus a variety of subdominant nongrassy herbs (1). They are highly nutritious plants and, from long adaptation to the climate, have the hardiness to withstand extremes of drought, cold, plant disease, plant competition, and the general rigors of the habitat.

The generally rolling plains are deeply etched in some places by the Missouri River and its numerous tributaries. The Black Hills

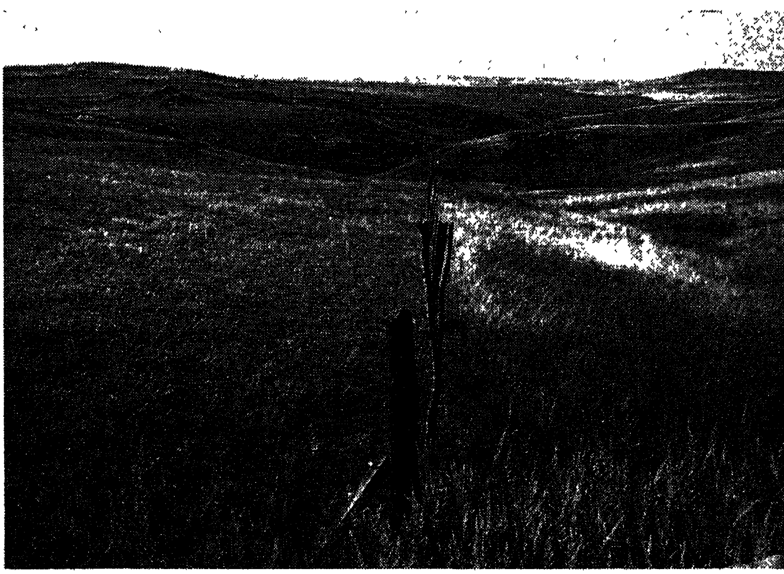

FIG. 1.—On the right of the fence line is climax mixed prairie, complete with an overstory of western wheatgrass and needle grass and understory of buffalo grass, blue grama, Pennsylvania sedge, yellow sedge, and thread-leaf-sedge, plus a sprinkling of nongrassy herbs such as pasqueflower, false mallow, biscuit root, mountain lily, beardtongue, Townsend's aster, and wild alfalfa, near Mandan, N. D. To the left of the fence mixed prairie is in the preliminary stages of breaking down. The midgrasses have been greatly depleted, the short grasses and sedges have increased slightly in density, and fringed sage, which is unpalatable to cattle, has become prevalent.

[4]Figures in parenthesis refer to "Literature Cited", p. 887.

of South Dakota and the Little Rocky Mountains and other small ranges rear high above the typical plains. The deep shady canyons of the rivers, the cool north slopes, and the warm dry slopes and the high crests of the mountains provide profound modifications in the local climate and the surviving descendants of a number of ancient climax communities that have moved across the plains in the past are found in the canyons, mountains, and slopes of this region. These stragglers from former reigning climaxes have persisted in these local compensatory sites. Sufficient fossil and modern evidence is available to reconstruct the patterns of the primeval plant associations as well as those of geologic antiquity.

After the Rocky Mountain uplift of the late Cretaceous period the fossil records of grass became more prominent as borne out by the numerous deposits throughout the following Tertiary period in Nebraska, Kansas, Colorado, and South Dakota. The study of ancient specimens has thrown considerable light on the vegetation, climate, and habitat of that epoch. Photographs of age-old needlegrass, *Stipa kansasensis*, made by Maxim K. Elias, paleobotanist at the University of Nebraska, in 1931, indicate a striking similarity to the present needlegrass of our Great Plains. Elias and others, found, in the deposits with the ancient needlegrass, other plant associates such as hackberry, *Celtis willistonii* and stickseed, *Krynitzkia coroniformis*. Likewise, these fossils show a remarkable resemblance to the common hackberry, *Celtis communis*, and stickseed, *Krynitzkia sp.*, of the Great Plains. These studies have given background for the belief that the climate of that remote age was semiarid, though probably less so than now.

Elias states that these plant remains were collected also in the unsorted continental deposits of early Pliocene geologic age where they were associated with the fossil bones of *Pliohippus leidianus*, the Pliocene ancestor of our modern horse. It is believed that the Pliocene geologic formation represented the flood plain habitat of the Rocky Mountains piedmont. The undisturbed condition of the plants indicates that they were buried close to their place of growth.

Clements and Chaney state, "It is probable that the evolution of grassland proceeded more rapidly in the period of mountain-making in the Upper Oligocene to produce the forerunner of the modern prairie in the Miocene, where the typical genus *Stipa* is recorded, along with horses of the grazing type, *Merrychippus* and *Protohippus*."

The evidence indicates a great multiplication of grass species between early Tertiary periods and the Pleistocene (ice age). With the major climatic changes brought on by the various glacial pulsations of Pleistocene times came a vast mingling of plant climaxes that had heretofore been separated by half a continent.

With the downward flexure of the glaciers came a simultaneous winter climate that made the plants and animals of the invaded regions shunt slowly south to avoid extinction. This was not difficult as the time period involved for the advancement and recession of the glacier is estimated to be many thousands of years. Therefore, as the

equable conditions of the north were contracting before the glaciers, they were expanding on the south.

These migrating climates have had a profound effect on the plains plant communities and have altered them quite measurably in terms of preglacial communities. The glaciers pushed the wheatgrasses, *Agropyrons*, *Koeleria*, needlegrasses, *Stipas*, fescues, *Festucas*, and blue grasses, *Poas* of northern origin into the southern plains and southwest. As the glaciers receded and were followed back to the polar cap by a warm dry spell, the gramas, *Boutelouas* buffalo, *Buchloe*, and three-awned grasses, *Aristidas*, and galleta, *Hilaria*, moved north from their place of origin on the Mexican plateau. During the Nebraskan and Kansan Glacial epoch the tall bluestem grasses, *Andropogons*, now climax in the coastal prairie of Texas, were pushed ahead of the hardwood forests in a westerly direction from their southeastern homeland. The great shrub, sagebrush, *Artemisia* (Fig. 2), rabbit brush, *Chrysothamnus*, and saltbush, *Atriplex*, migration from out of the Great Basin into Wyoming and southern Montana is presumed to have taken place following a warm dry period succeeding one of the glacial retreats. Remnants of Palouse prairie dominants extend all the way across Montana to the North Dakota Badlands and to the Black Hills of South Dakota. The major dominant of this relict is spiked wheatgrass, *Agropyron spicatum* (Fig. 3), and persists on the north slopes of hills and in loose talus and scoria, and Sandberg's blue, *Poa secunda*, or other closely allied bluegrasses. Sandberg's blue, also a member of the Palouse prairie association, is widespread over the northwest portion of the

FIG. 2.—Grassland—sagebrush savannah, Little Power River, Wyo. Sagebrush grows more vigorously in the lowlands as seen in the foreground and sparsely on the well-drained uplands, as noted in the background.

FIG. 3.—Relict *Ponderosa* pine and *Agropyron spicatum* on steep rocky slope and mixed prairie in the more level foreground, near Miles City, Mont.

Northern Plains now and increases in density materially during drought and on heavily used ranges, where blue grama, western wheat, and needle-and-thread have been sacrificed. This presupposes that the Palouse prairie association formerly extended across Montana and northern Wyoming during a glacial advance when a winter and spring rainfall climate existed that was quite comparable to that of the Palouse prairie region today.

Scattered throughout are odd remnants of older climaxes. For instance, needle-and-thread, now a climax dominant of the mixed prairie of the Northern Great Plains and southern Canadian prairie, is found as a relict on the south banks of the Yukon in Alaska. Blue grama, which now is a dominant only as far north as Youngstown, Canada, formerly had a much more extensive range northward and can be found as a relict on dry south hillsides along the Saskatchewan near Edmonton, Canada. Buffalo grass runs out northward near Plentywood, Montana, and only extends westward to Ft. Peck, Mont.; Gillette, Wyo.; and the Laramie Valley in Wyoming. Blue grama is only found as an occasional relict in the Red Desert of Wyoming and its general westward extension lies along the foothills of the Rocky Mountains, although a few communities have been reported in the Palouse region There are a few isolated communities of galleta grass near Rawlins and Church Butte, Wyo., yet there is a considerable skip before it is found again in east central Colorado and farther south where it becomes dominant. The bluestem grasses, relicts from a warm, moist climatic phase, occupy north hillsides, sandy soils, or valley bottoms over most of the western Dakotas and eastern Montana and Wyoming where they find the moisture

FIG. 4.—North hillside communities of *Ponderosa* pine forming savannah with mixed prairie on Pine Ridge Indian Reservation, S. D.

compensation more in line with their requirements. Little bluestem grows on the breaks of the Milk River in Montana almost to the Rocky Mountains and has been reported as well along the foothills of the Windriver Mountains (2). Thread-leaf sedge or niggerwool (*Carex filifolia*), an important grazing plant in the Northern Plains, practically runs out at the South Platte River, whereas buffalo grass, one of the major dominants of the South Plains, becomes less and less important north of the South Platte River until it completely runs out near the Canadian border.

Evidence that the plants from cooler, moist, northern climates were pushed ahead of the southern glacial advance is indicated by the presence of western yellow pine, *Pinus ponderosa* (Fig. 4) and quaking aspen, *Populus tremuloides*, in many of the hills and river breaks in the Northern Great Plains. Paper birch, *Betula papyrifera*, common in the northern forests, is found in the Black Hills of South Dakota. White spruce, *Picea canadensis*, is found within narrow limits in the Black Hills, and has the same northward origin. Oak, *Quercus macrocarpa*, is a remnant of a previous eastern oak-hickory advance during a moist period and now its growth is restricted to the Black Hills, river valleys, and north hillsides in many places. The dominants and subclimax species of the eastern oak-hickory forests, namely, oak, hickory, *Hicoria*, ash, *Fraxinus*, elm, *Ulmus*, and cottonwood, *Populus* grow in great stringers along the flood plains of the drainages and in few instances minor lumbering enterprises have developed along the Missouri River and other major drainages.

OBJECTIVE

The following discussion enumerates the main plants that provide the bulk of the forage eaten by grazing animals on mixed prairie ranges. These plants are classified according to kind and to the season which they provide the most and best forage (Table 1). Plant indicators that mark the downward changes in these grazing lands are described as well.

The information has been drawn from grazing inventories made by the Soil Conservation Service on about 14 million acres of land in

soil conservation districts, demonstration projects, and Indian reservations from 1936 until the present.

GENERAL SIGNIFICANCE OF MAJOR FORAGE PLANTS AND CONDITIONS FOUND IN MIXED PRAIRIE GRAZING LANDS

The mixed prairie is sometimes called the short grass country. Rainfall varies between 12 and 20 inches a year and the annual evaporation amounts to about 45 inches in the south to approximately 30 inches in the north. As an average, half of the rainfall comes during the growing season between April 1 and September 1. Fluctuations in climate are common and following these fluctuations may come marked effects on the growth of vegetation. For example, perennial grass plots at Huron, S. D., were found to yield at the rate of 300 pounds of dry forage per acre in the drought year of 1937, whereas the same area yielded about 1,800 pounds of dry forage per acre in the wet year of 1944.

The mixed prairie is represented by several hundred plants. However, only a few dominant ones give special characterization to the area and these rank highest in forage production and give the best protection to the soil as well.

The mixed prairie supports nearly one-fourth of the livestock in the United States west of the 98th meridian. It is one of the foremost grazing grounds in the nation. Much of the forage cures on the stalk in form of natural hay and a good deal of that which is not used in the growing period is grazed during favorable late fall and winter periods.

Here the cool season needle grasses, wheat grasses, blue grasses, and sedges from the northern mid-latitudes grow in harmony with the warm season gramas and buffalo grasses which originated in the warm southwest (3). The associated nongrassy herbs also have different seasonal growth habits. Therefore, these plant combinations provide nutritious grazing during the entire growing season. The needle grasses, wheat grasses, blue grasses, and sedges are highly palatable in the spring. They complete their growth cycle during the spring period of high rainfall and low evaporation. Western wheatgrass and needle-and-thread are also prized by livestock as dry feed on snowy winter ranges. Sheep should not graze needle-and-thread at the time of seed formation as they may become injured by the sharp awns of the seed.

During years of summer drought, the early crop of cool season grasses provides most of the grazing for the remainder of the year. The grasses are usually mature in time to avoid the feeding season of grasshoppers. Unless heavy grasshopper infestations occur, the matured and tougher early grasses usually escape much damage, whereas the more tender grama and buffalo grass and summer growing nongrassy herbs may be eaten completely. However, under heavy grasshopper infestations even the matured midgrasses are eaten.

Early green feed is at a premium, especially during the lambing and calving season. As a result, the cool season grasses are often overgrazed and killed out. To meet the need for more early forage, many ranchers are planting part of their farmland to crested wheatgrass,

TABLE 1.—*Seasonal grazing period of dominant plants in mixed prairie association.*

Season of growth	Mid-grasses	Short grasses and dryland sedges	Nongrassy herbs
Spring	Needle-and-thread, *Stipa comata;* western wheatgrass, *Agropyron smithii;* prairie junegrass, *Koeleria cristata;*	Yellow sedge, *Carex stenophylla;* Penn. sedge, *Carex pennsylvanica;* thread-leaf-sedge, *Carex filifolia;* Sandberg bluegrass, *Poa secunda;*	Palatable: Pasqueflower, *Anemone ludoviciana* Mountain lily, *Leucocrinum montanum* Biscuit root, *Cogswellia foeniculaceum* False mallow, *Malvastrum coccineum* Unpalatable: Townsend's aster, *Aster townsendii* Golden groundsel, *Senecio aureus* Loco, *Astragalus spp.*
Early summer		Blue grama, *Bouteloua gracilis;* buffalo grass, *Buchloe dactyloides;*	Palatable: Wild alfalfa, *Psoralea floribunda* White prairie clover, *Petalostemon candidus* Purple prairie clover, *Petal ostemon purpureus* Silver lupine, *Lupinus argentus* Beardtongue, *Penstemon spp.* Unpalatable: Indian paintbrush, *Castelleia integra* Verbena, *Verbena bipinnatifida* Loco, *Astragalus spp.*
Late summer and early fall	Needle-and-thread; western wheatgrass; prairie junegrass	Yellow sedge; Penn. sedge; thread-leaf-sedge; sandberg bluegrass	Palatable: Blazing star, *Liatris punctata* Hairy golden aster, *Chrysopsis villosa* False prairie boneset, *Kuhnia glutinosa* Unpalatable: Many flowered aster, *Aster multiflorus* Missouri goldenrod, *Solidago missouriensis* Tarragon, *Artemisia dracunculus*

the naturalized Siberian cousin of western wheatgrass. Crested wheatgrass can be grazed earlier than the early natives and produces over twice the grazing, according to present information.

Of the summer growing short grasses, namely, blue grama, buffalo grass, and hairy grama, blue grama is the only one having general distribution. It is the most common plant in the mixed prairie. In point of feed value throughout the year, blue grama, hairy grama, and buffalo grass are the most nutritious of all native grasses in mixed prairie. Their leaves are notable for their remarkable starch sheaths and the protein content ranks high along with the other better native grasses throughout the year.

Nongrassy herbs are neither as plentiful nor of such high quality in mixed prairie as in the neighboring humid prairies (7). Those in mixed prairie do not have the supply of deep subsoil moisture to draw on that is available in the more humid eastern prairies. They are more nearly in competition with the grasses for water and soil nutrients because they have a large per cent of surface roots which compete with the grasses (8). Under heavy grazing the edible ones are killed outright, while unpalatable ones increase. Many nongrassy herbs, including unpalatable ones, were killed during the drought of the thirties (6). The good ones have increased more slowly than the grasses and are needed to give variety to many well-grassed ranges.

As indicated in Table 1, individual species of nongrassy herbs are more numerous than grasses for they produce less volume and cover less ground space; however, they provide variety to the animal diet as well as considerable forage. An excellent range will have a variety of these plants distributed throughout. Several ranges in western South Dakota were sampled in 1938. The average of the total air-dried forage produced per acre was nearly one thousznd pounds. Of this total 150 pounds per acre, or 15%, came from edible nongrassy herbs.

PLANT INDICATORS THAT MARK THE DOWNWARD TREND IN MIXED PRAIRIE

Breaking down of productive grasslands has a profound effect on the economy and welfare of ranches and communities. Thus, it is important that graziers recognize the early symptoms of grassland deterioration and take immediate steps to improve the ranges. Indicator plants that mark the several stages in the depletion of mixed prairie are enumerated.

MIXED PRAIRIE GRASSES THAT FIRST GO OUT UNDER HEAVY GRAZING AND DROUGHT

Needle-and-thread (4), western wheatgrass, and prairie junegrass, all grasses of medium height, are the first ones grazed out under heavy use, or killed back by spring drought. Because of their erect growth, it is easier for livestock to eat off a larger percentage of their food-building leaves than those of the low-growing short grasses and sedges. Almost total removal of these midgrasses from mixed prairie

and the subsequent thickening of the short grasses and sedges is one of the first indications that mixed prairie is on the downgrade.

PALATABLE NONGRASSY HERBS THAT DECREASE UNDER HEAVY GRAZING OR DROUGHT

The displacement of the more edible nongrassy herbs parallels the loss in the number of cool climate midgrasses. This condition is characteristic of the change from excellent to a poorer condition as the more palatable nongrassy herbs are greatly reduced and those that remain are generally low on vigor.

The most important ones are as follows:

Legumes

White prairie clover, *Petalostemon candidus*
Purple prairie clover, *Petalostemon purpureus*
Wild alfalfa, *Psoralea floribunda*
Silver lupine, *Lupinus argentus*

Other Nongrassy Herbs

Pasqueflower, *Anemone ludoviciana*
Mountain lily, *Leucocrinum montanum*
Blazing star, *Liastris punctata*
False mallow, *Malvastrum coccineum*
Biscuit root, *Cogswellia ludoviciana*
Beardtongue, *Penstemon spp.*
Hairy golden aster, *Chrysopsis villosa*
False prairie boneset, *Kuhnia glutinosa*

GRASSES AND SEDGES THAT INCREASE FOLLOWING THE FIRST STAGE IN THE DEPLETION OF EXCELLENT MIXED PRAIRIE GRASSLANDS

Without competition of midgrasses and highly palatable nongrassy herbs, the short grasses and sedges fill in the vacated areas, and usually develop a denser sod than before. These plants are among the more drought-resistant perennials. The major grasses and sedges under consideration are named as follows:

Buffalo grass, *Buchloe dactyloides*
Blue grama, *Bouteloua gracilis*
Hairy grama, *Bouteloua hirsuta*
Penn. sedge, *Carex pennsylvanica*
Sandberg's bluegrass, *Poa secunda*
Yellow sedge, *Carex stenophylla*
Thread-leaf-sedge, *Carex filifolia*

When these plants are found in the state of continuous unbroken sod, they represent the second stage below best condition. Grazing lands should not be allowed to fall below this stage. The forage is highly nutritious and the soil is protected, but the length of season has been shortened and the grazing capacity somewhat reduced. Continued overuse or drought soon thins out the cover and leaves openings for less favorable plants. Sandberg's bluegrass is the most durable of the lot as it is a heavy seeder, grows early in the spring, and evades dry weather and warm temperatures. It increased during the drought of the thirties but was rapidly replaced by the gramas and midgrasses after three years of better rainfall.

MIXED PRAIRIE NONGRASSY HERBS THAT INCREASE UNDER HEAVY GRAZING

When a large part of the edible grasses and nongrassy herbs are killed out, they are replaced by numerous comparatively unpalatable nongrassy herbs. These plants find an easy opportunity to multiply in numbers and often in size through lack of competition for moisture, soil nutrients, and sunlight.

Some of the most common ones are listed below:

Golden groundsel, *Senecio aureus*
Loco, *Astragalus spp.*
Verbena, *Verbena bipinnatifida*
Many-flowered aster, *Aster multiflorus*
Fringed sage, *Artemisia frigida*
False tarragon, *Artemisia dracunculus*
Rush skeleton weed, *Lygodesmia juncea*
Curly cup gumweed, *Grindelia squarrosa*
Gaura, *Gaura spp.*
Virginia spiderwort, *Tradescantia virginiana*
Missouri goldenrod, *Solidago missouriensis*
Phlox, *Phlox hoodii*
Cactus, *Opuntia spp.*
Broom snakeweed, *Gutierrezia sarothrae*

ANNUAL GRASSES AND WEED INVADERS THAT INCREASE ON DEPLETED MIXED PRAIRIE

There are a great many annual grasses and weeds that occupy the mixed prairie when the highly productive perennials have been killed out or severely weakened.

Grazing lands heavily infested with these plants are usually in the last stages of deterioration. During excessively high rainy periods the spring growers like little barley may develop a dense spring cover on well-sodded buffalo grass and blue grama ranges. Little barley is a heavy feeder on moisture and the short grasses can be severely damaged if a dry summer follows. If a reasonably wet summer prevails, the short grasses may survive uninjured. Many of these invading annuals produce considerable palatable feed. However, they are not as productive as the native perennials they have displaced. They are short-lived, hence have a tendency to dry up, blow away, and leave the soil bare. Their dead root systems are poorly developed and inferior to the native perennials.

The more common of these annuals are:

Lambs quarter, *Chenopodium album*
Russian thistle, *Salsola pestifer*
Woolly Indian wheat, *Plantago purshii*
Sunflower, *Helianthus annuus*
Peppergrass, *Lepidiumdensi florum*
False buffalo, *Monroa squarrosa*
Six weeks' fescue, *Festuca octoflora*
Witches' broom, *Panicum capillare*
Japanese chess, *Bromus japonicus*
Cheatgrass brome, *Bromus tectorum*
Little barley, *Hordeum pusillum*

SUMMARY

1. Individual native grazing plants, whether grasses, shrubs, or nongrassy herbs, have distinctive growth habits and feeding values. The native forage crop is composed of many species, thus making its management more difficult than a single farm crop like corn or alfalfa.
2. The mixed prairie is composed of climax midgrasses, short grasses, and dryland sedges, plus a variety of subdominant nongrassy herbs.
3. Grasses and other vegetation have been modified throughout the ages as environment has been changed by shifting climates.
4. The mixed prairie supports nearly one-fourth of the livestock in the United States west of the 98th meridian.
5. The cool season midgrasses, and palatable nongrassy herbs, are the first plants to go out under heavy grazing and drought.
6. The drought-resistant summer-growing short grasses, dryland sedges, Sandberg bluegrass, and unpalatable nongrassy herbs increase during the first stages in the depletion of excellent mixed prairie grasslands.
7. The following annual grasses and weeds increase on depleted mixed prairie ranges: Lambs quarter, Russian thistle, Woolly Indian wheat, sunflower, peppergrass, six weeks' fescue, witches' broom, Japanese chess, cheatgrass brome, little barley, and false buffalo.

LITERATURE CITED

1. ALLRED, B. W. The significance of grassland ecology to the Northern Great Plains. Soil Conservation Service, Region Five, Lincoln, Nebr. 1941.
2. CLEMENTS, F. E. The relict method of dynamic ecology, Jour. of Ecol., Vol. XXII, No. 1 page 43.
3. ———, and SHELFORD, V. E. 1934. Bio-ecology, New York: John Wiley & Son. 1939 (Pages 251–277.) 000:00–00. 1939.
4. SARVIS, J. T. Effects of different systems of grazing and intensities of grazing upon the native vegetation at the Northern Great Plains Field Station. U.S.D.A. Bul. 1170. 1923.
5. WEAVER, J. E., and CLEMENTS, F. E. Plant Ecology, New York: McGraw-Hill Book Co. 1929. (Pages 458–469.)
6. ———, and FITZPATRICK, T. J. The prairie. Ecological Monographs, 4:110–295. 1934.
7. ———, and HANSEN, W. W. Native midwestern pastures—their origin, composition, and degeneration. Univ. Nebraska Conservation and Survey Division. 1941.
8. ———. Regeneration of native midwestern pastures under protection. Univ. Nebraska Conservation and Survey Division. 1941.

EFFECT OF SODIUM NITRATE AND AMMONIUM FERTILIZERS ON THE PERMEABILITY OF WESTERN SOILS[1]

MILTON FIREMAN, O. C. MAGISTAD, AND L. V. WILCOX[2]

SODIUM nitrate is one of the most widely used nitrogenous fertilizers. The results of experimental findings, especially in eastern United States, have given this material a high evaluation, and have shown in a general way how and when it should be used to best advantage. However, since sodium salts deflocculate soil colloids to a considerable extent, the continuous application of sodium-containing fertilizers in large quantities to some soils, particularly to those that are high in colloidal matter, often results in a poor physical condition in the soil. While this has been known and taught for many years, few data are available to indicate the magnitude of the changes which occur in the soil as a result of sodium fertilizer applications.

Some western farmers, who had not used sodium fertilizers previously, were concerned in 1942 at the prospect of using sodium nitrate because of its possible deleterious effect on the soil. This study was undertaken to determine in the laboratory whether the effect of sodium-containing fertilizers on the physical properties of soils, and especially on soil permeability, is a widespread problem or the result of special circumstances.

LITERATURE REVIEW

The influence of sodium nitrate on the physical condition of the soil was discussed by Hall (7)[3] in England in 1904 and by Gans (5) in Germany in 1905. Hall found that regular yearly applications of sodium nitrate at the rate of 500 to 1,000 pounds per acre (not unusual applications for truck crops in England) induced very bad tilth in some soils. The evidence was conflicting, however, for sodium nitrate converted some soils into concrete-like masses, while other soils nearby showed little evidence of bad tilth, except occasionally in wet winters, despite 50 successive annual applications of 225 pounds of sodium nitrate per acre. Somewhat similar results were later reported by Brown (2) in this country and Hardon (8) in Sumatra, among others. However, little stress has been laid in humid regions upon deterioration in soil structure as a result of sodium-containing fertilizer applications.

There are few data available to indicate the best practice of nitrogen fertilization in arid regions. Kelley and Thomas (11) reported in 1920 that large applications of sodium nitrate caused "alkali injury" in an experimental plot. Huberty and Pillsbury (10) have shown that both sodium nitrate and ammonium sulfate reduced the rate at which a California soil would take water when irrigated. Aldrich, *et al.* (1) conclude: "On certain soil types, it is likely that the continued

---

[1]Contribution from the U. S. Regional Salinity Laboratory and the Division of Irrigation Agriculture, Bureau of Plant Industry, Soils and Agricultural Engineering, Agricultural Research Administration, Riverside, Calif., in cooperation with the eleven western states and the Territory of Hawaii. Received for publication June 2, 1945.

[2]Associate Soil Scientist, Director of U. S. Regional Salinity Laboratory, and Agronomist, Division of Irrigation Agriculture, respectively. The authors wish to acknowledge the assistance of Mary Chase Erwin in obtaining some of the permeability data.

[3]Figures in parenthesis refer to "Literature Cited", p. 901.

application of large or poorly distributed doses of either of these fertilizers (sodium nitrate and ammonium sulfate) in the absence of organic matter will bring about serious structural deterioration".

EXPERIMENTAL PROCEDURE

The soils for this study were obtained from representative irrigated regions in nine western states, usually through an official collaborator of this Laboratory. In some cases, samples of problem soils were obtained, but on the whole the samples received were representative of the irrigated areas. It should be pointed out that the majority of these soils were calcareous, as are most western soils.

The soils were air-dried, crushed to pass a 2-mm sieve, and carefully mixed. Preparation of the soil for the study consisted of packing the soil (4) into No. 2 tinned cans (permeameters) previously provided with suitable water inlets and outlets. The water used was, as far as possible, identical with that used in regular irrigation practice upon the soil in question. Rather than transport large quantities of water for these tests, representative samples were obtained and analyzed, and the results of these analyses were used in making up the test waters. The results of the water analyses are given in Table 1.

The appropriate water was applied to each set of soil columns through a constant head device (4), which kept the water head at exactly the same level in all replicates of each soil. The water which passed through the soil was collected and measured, and the permeability calculated in inches per hour per unit potential gradient (4), taking into account the length of the water column, the length and area of the soil column, and the quantity of water which passed through the column in unit time. In most cases, about 12 inches of water percolated through the soil; however, in a few soils, the permeability was so low that only 6 inches of water percolated. All comparisons of permeability were made, therefore, at permeability values corresponding to 6 inches of percolation. Values given are the average of triplicate determinations.

While the exact quantitative relationship which may exist between field response and laboratory behavior to sodium nitrate applications is not known, the results obtained in the laboratory are qualitatively in close agreement with those obtained in the field. In addition, results are much more quickly and inexpensively obtained in the laboratory and have proved to be extremely useful in consideration of practical problems of immediate importance.

EXPERIMENTAL RESULTS

TESTS WITH SODIUM NITRATE

In preliminary experiments, sodium nitrate was applied to the packed soil columns in various ways in attempts to simulate field practices. It was (a) applied in the irrigation water, (b) mixed with the soil, and (c) broadcast over the soil surface. The results obtained on one of the soils tested are shown in Fig. 1. It will be noted that when the sodium nitrate was applied in the irrigation water at the rate of 395 pounds per acre foot of water (145 p.p.m.), there was no significant decrease in permeability as compared with the untreated samples. On the other hand, when the same *quantity* of sodium nitrate was applied to the soil in ½ inch of irrigation water at the rate of 9,480 pounds per acre foot of water (3,490 p.p.m.) and was followed by normal irrigation water, the permeability decreased markedly. Somewhat similar decreases in permeability were caused by the application of 395 pounds per acre of sodium nitrate mixed with the soil or broadcast over the surface.

From the results of these and other tests, it is found that if sodium nitrate is applied at *low rates* in most irrigation waters there is no appreciable reduction in the rate at which water enters the soil. But

TABLE 1.—*Analyses of waters used for the field irrigation of the soils studied, synthetic waters, approximating in composition the natural waters, being used in the permeability tests.*

Soil No.	Water analysis No.	$K \times 10^5$ @25° C	T.D.S., p.p.m.	Na, %*	Cl, %†	Equivalents per million								SiO₂, p.p.m.
						Ca	Mg	Na	K	CO_3 + HCO_3	SO_4	Cl	NO_3	
316	Bul. 292, N.M.A.E.S. Well No. 1	—	242	26	3	2.02	0.58	0.45	0.08	3.15	0.29	0.12	—	32
317	Bul. 292, N.M.A.E.S. Well No. 2	—	512	86	7	0.63	0.39	7.80	0.13	5.90	0.93	0.51	—	62
318	Bul. 263, N.M.A.E.S. Pecos Irrig. water	—	3,855	40	37	27.5	11.5	27.5	2.25	0.95	31.2	18.6	—	15
319	Bul. 263, N.M.A.E.S. Rio Grande Irrig. water	—	548	34	22	4.28	1.19	3.07	0.36	1.87	3.90	1.69	—	21
320	Rubidoux Lab. 16891	40.9	256	6	4	2.92	1.32	0.29	0.12	4.16	0.11	0.03	0.14	30
321	Rubidoux Lab. 16892	36.0	218	3	1	2.60	1.20	0.13	0.03	2.92	0.87	0.02	Trace	6
322	Rubidoux Lab. 16893	52.2	316	17	1	2.94	1.90	1.03	0.05	4.31	1.41	0.06	Trace	6
323	Rubidoux Lab. 16894	25.9	164	19	7	1.60	0.59	0.56	0.13	2.23	0.19	0.10	0.07	20
324	Rubidoux Lab. 16895	42.3	262	23	6	2.74	0.69	1.04	0.14	3.86	0.29	0.19	0.06	26
325	Rubidoux Lab. 10395	6.31	53‡	29	14	0.20	0.26	0.19	—	0.62	Trace	0.10	Trace	—
326	Rubidoux Lab. 10394	5.92	52‡	20	19	0.36	0.11	0.12	—	0.59	Trace	0.14	0	—
327	Rubidoux Lab. 10394	5.92	52‡	20	19	0.36	0.11	0.12	—	0.59	Trace	0.14	0	—
328	Rubidoux Lab. 16951	42.5	278	11	5	2.82	1.06	0.50	0.05	2.43	1.75	0.15	0.05	12
329	Rubidoux Lab. 16951	42.5	278	11	5	2.82	1.06	0.50	0.05	2.43	1.75	0.15	0.05	12
330	U.S.G.S. Paper 774, P. 174, Snake River water§	—	380	28	19	2.60	1.81	1.74	0.14	3.28	1.69	1.18	0.04	34
	U.S.G.S. Paper 774, P. 174, Snake River water§	—	207	12	7	2.50	1.07	0.52	0.07	2.93	0.81	0.28	0.05	20
331	U.S.G.S. Paper 774, P. 174, Snake River water§	—	380	28	19	2.60	1.81	1.74	0.14	3.28	1.69	1.18	0.04	34
	U.S.G.S. Paper 774, P. 174, Snake River water§	—	207	12	7	2.50	1.07	0.52	0.07	2.93	0.81	0.28	0.05	20
332	Rubidoux Lab. 16983	71.1	403	47	43	2.20	1.33	3.27	0.11	2.97	0.97	2.96	0.04	21
333	Rubidoux Lab. 16983	71.1	403	47	43	2.20	1.33	3.27	0.11	2.97	0.97	2.96	0.04	21
334	Rubidoux Lab. 16983	71.1	403	47	43	2.20	1.33	3.27	0.11	2.97	0.97	2.96	0.04	21
335	Rubidoux Lab. 16982	244.0	1,459	69	64	4.42	2.69	16.52	0.15	4.85	3.84	14.53	0.60	38
336	Rubidoux Lab. 16950	115.0	835	40	7	5.08	2.52	5.05	0.09	4.91	6.82	0.70	0.25	15

337	Rudiboux Lab. 16952	92.2	620	37	17	4.37	1.64	3.58	0.13	3.96	4.05	1.45	0.22	20
338	Rubidoux Lab. 16858§	33.2	224	24	10	2.00	0.52	0.84	0.18	2.67	0.49	0.20	0.14	31
	Rubidoux Lab. 16859§	12.4	96	19	6	0.78	0.23	0.25	0.07	1.06	0.15	0.08	0	30
339	Rubidoux Lab. 16953	137.0	870	49	42	4.60	2.34	6.83	0.12	3.42	4.55	5.71	0.04	14
340	Rubidoux Lab. 16951	42.5	278	11	5	2.82	1.06	0.50	0.05	2.43	1.75	0.15	0.05	12
341	Rubidoux Lab. 17031	49.6	308	23	12	2.56	1.39	1.22	0.11	3.46	1.08	0.60	0.01	26
342	Rubidoux Lab. 17032	111.0	673	40	27	3.00	3.74	4.79	0.52	7.08	1.55	3.01	0.11	24
343	Rubidoux Lab. 17033	178.0	1,176	39	40	4.83	6.09	7.36	0.48	4.46	6.49	7.41	0.01	20
344	Rubidoux Lab. 17034	79.8	491	29	23	3.58	2.27	2.45	0.14	4.41	2.00	1.85	0.04	17
345	Rubidoux Lab. 17035	37.1	210	3	2	2.48	1.51	0.13	0.04	3.81	0.13	0.10	Trace	8
346	Rubidoux Lab. 17042	25.2	164	27	8	1.14	0.73	0.73	0.08	2.23	0.31	0.20	0.02	28
347	Rubidoux Lab. 17042	25.2	164	27	8	1.14	0.73	0.73	0.08	2.23	0.31	0.20	0.02	28
348	Rubidoux Lab. 12429	9.82	68	26	9	0.59	0.17	0.27	—	0.76	0.08	0.05	0.03	—
349	Rubidoux Lab. 12429	9.82	68	26	9	0.59	0.17	0.27	—	0.76	0.08	0.05	0.03	—
350	Rubidoux Lab. 12429	9.82	68	26	9	0.59	0.17	0.27	—	0.76	0.08	0.05	0.03	—
351	Leffingwell Lab. 1931 Hills Bros. Ranch Well No. 9§	—	360	52	7	1.95	0.33	2.43	—	1.88	2.50	0.34	0	14
	Leffingwell Lab. 1931 Hills Bros. Ranch Well No. 11§	—	464	47	7	3.05	0.25	2.91	—	1.79	3.96	0.45	0	18
352	Rainwater	—	—	—	—	—	—	—	—	—	—	—	—	—
353	C.E.S., A. J. Thille¶	131.0	1,094	31	11	7.30	3.46	4.92	—	5.55	8.23	1.66	Trace	—
354	Rubidoux Lab. 14084	168.0	1,340	26	11	9.19	5.29	5.04	—	4.86	12.39	1.90	0.29	—
355	C.E.S., J. Fowler	41.1	448	23	24	2.35	1.30	1.13	—	2.95	0.53	1.15	0.21	—
356	Am. Geo. Un. III, 1941, p. 667	—	151	33	15	0.70	0.70	0.70	—	1.40	0.20	0.30	0.10	—
357	C.E.S. 2833	16.7	70	34	15	0.7	0.6	0.6	—	1.4	0.2	0.3	0.1	—
358	C.E.S. 2867	98.0	576	55	65	3.3	0.9	5.0	—	1.7	1.5	6.0	0.1	—
359	C.E.S. 2863	51.0	503	38	12	3.0	1.1	2.5	—	4.5	1.3	0.8	0.1	—
360	Rubidoux Lab. 16948	77.2	472	44	19	2.91	1.68	3.60	0.08	5.30	1.32	1.25	0.32	26
361	Rubidoux Lab. 16949	23.1	140	15	3	1.46	0.52	0.37	0.07	1.98	0.28	0.05	0.01	16
362	C.E.S. (1941) Wing.	42.5	345	28	9	2.70	0.58	1.26	—	3.40	0.69	0.42	Trace	—
366	Rubidoux Lab. 17006	144.0	1,090	23	16	7.39	4.89	3.78	0.11	3.91	9.79	2.35	0.27	30
367	C.E.S. 3273§	152.0	724	58	26	4.20	2.30	9.15	—	8.05	3.45	4.15	—	—
	C.E.S. 3274§	179.0	1,300	59	31	4.90	2.72	10.68	—	8.60	4.15	5.65	—	—
368	Rubidoux Lab. 17021	113.0	698	28	44	4.67	3.42	3.22	0.09	4.85	1.58	4.96	0	41
369	Rubidoux Lab. 17022	93.7	652	19	19	4.67	3.29	1.94	0.07	4.01	3.99	1.80	0.13	40

*The percentage of sodium, in equivalents, to total bases.
†The percentage of chloride, in equivalents, to total bases.
‡Calculated.
§Synthetic water used in laboratory average of two analyses.
¶C.E.S. = Citrus Experiment Station, Riverside, Calif.

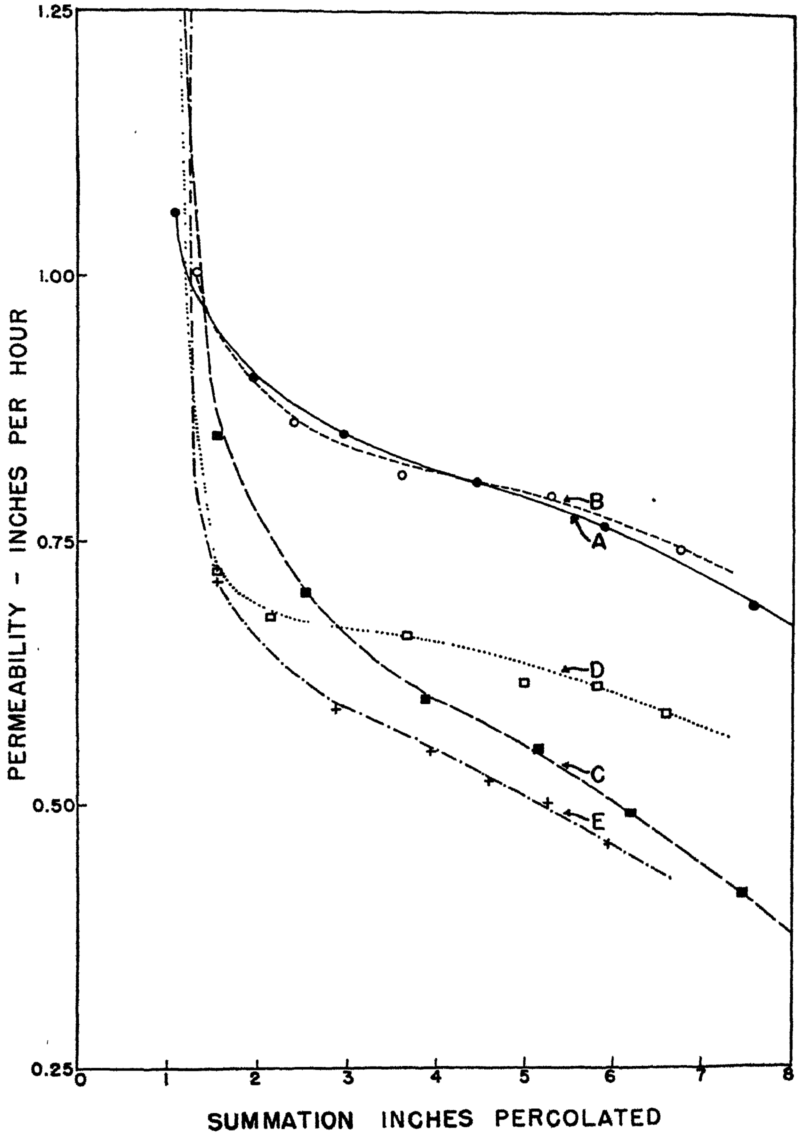

Fig. 1.—Variation in permeability of Fallbrook fine sandy loam with manner of sodium nitrate application. A, untreated; B, 395 pounds per acre foot of water (145 p.p.m.), 12-inch irrigation; C, 9,480 pounds per acre foot of water (3,490 p.p.m.), ½ inch applied, followed by normal irrigation water; D, 395 pounds per acre, mixed in surface inch of soil; E, 395 pounds per acre, broadcast on surface of soil.

if the rate of application is high, such as when bags of the salt are dumped into a weir, the permeability of the soil is markedly reduced.

However, much of the nitrogen fertilizer applied to truck crops is drilled in or applied in bands about 2 or 3 inches wide in rows 3 to 4 feet apart at rates of 200 to 500 pounds of the fertilizer per acre. This represents applications of from 2,400 to 12,000 pounds per acre for the area of the bands receiving the fertilizer. The application of sodium nitrate in the remainder of the laboratory studies herein reported was mixed into the surface inch of the soil sample at the rate of 1,000 pounds per acre based on the area of the soil column under test. The soil sample was assumed to represent the soil area of and in the immediate vicinity of the fertilizer bands. The fertilizer band is usually located between the irrigation furrow and the crop row, and a reduction in permeability in the vicinity of the band will restrict the movement of water to the plant roots.

Data for 51 western soils are given in Table 2. It will be noted that the untreated soils had an average permeability of 1.2 inches per hour to normal irrigation water. This permeability was reduced to 0.71 inch per hour, or by 41%, by a sodium nitrate application of 1,000 pounds per acre. Student's methods (13) for paired samples show this decrease to be highly significant.

A few of the soils have a very low permeability in their normal state. For example, soil 342 (Jordan loam from Utah) has a permeability in the laboratory of 0.013 inch per hour, which means over 400 hours would be required for a 6-inch irrigation. An application of sodium nitrate at the rate of 1,000 pounds per acre decreased the permeability of this soil from 0.013 to 0.006 inch per hour. While this is a large percentage decrease, it is a small absolute decrease, and is probably of little importance in a soil with such a low normal permeability. Few crops could be grown under such conditions. On the other hand, a few of the soils tested had extremely high permeabilities, as high as 6.8 inches per hour. Such soils are difficult to irrigate, and a decrease in soil permeability might conceivably be of considerable benefit to the farmer.

The effect of the addition of sodium nitrate in seriously reducing the permeability of a soil is shown in Fig. 2. In this case the permeability after 6 inches of percolation was about one-seventh that of the untreated soil. On the other hand, soil 327 from Washington showed no significant decrease from a similar application (Fig. 3).

Samples from both check plots and sodium nitrate plots from two experiment stations in Washington were packed as indicated above and one set treated with $NaNO_3$ at the rate of 1,000 pounds per acre. The results of permeability tests with these soils are given in Table 3.

These results indicate that at these experiment stations heavy field applications of sodium nitrate have markedly reduced soil permeability, and that on the basis of laboratory tests additional normal applications cause no appreciable further reduction in permeability. Both check plot soils, however, do respond adversely to sodium nitrate applications.

TESTS WITH AMMONIUM FERTILIZERS

For purposes of comparison, tests were run with ammonium nitrate and ammonium sulfate in the same manner as with sodium nitrate.

TABLE 2.—*Effect of sodium nitrate on permeability of western soils.*

Soil No.	Source of soil		Soil type	Permeability, inches per hour			Decrease in permeability	
	State	County		(a) not treated	(b) treated	Ratio a/b	Inches per hour	%
316	N. Mex.	———	Mimbres silty clay loam	0.93	0.61	1.52	0.32	34
317	N. Mex.	———	Mimbres silty clay loam, dark color phase	0.04	0.03	1.33	0.01	25
318	N. Mex.	———	Carlsbad silt loam	0.46	0.46	1.00	0	0
319	N. Mex.	———	Gila clay adobe	0.12	0.03	4.00	0.09	75
320	Mont.	———	Huffine silt loam	0.07	0.01	7.00	0.06	86
321	Mont.	———	Fairfield loam	2.47	1.98	1.25	0.49	20
322	Mont.	———	Simms silt loam	1.43	0.68	2.10	0.75	52
323	Mont.	———	Burnt Fork stony loam	2.39	1.42	1.68	0.87	41
324	Mont.	———	Grantsdale loam	1.19	0.79	1.51	0.40	34
325	Wash.	———	Not known	1.95	1.32	1.48	0.63	32
326	Wash.	———	Not known	0.89	0.55	1.62	0.34	38
327	Wash.	———	Not known	0.15	0.14	1.07	0.01	7
328	Wyo.	———	Laramie silt loam	2.12	1.65	1.29	0.47	22
329	Wyo.	———	Fort Collins fine sandy loam	3.19	2.40	1.33	0.79	25
330	Idaho	———	Decho loam	0.26	0.18	1.44	0.08	31
331	Idaho	———	Decho silty clay loam	0.34	0.22	1.55	0.12	35
332	Ariz.	———	Not known	1.35	0.55	2.46	0.80	59
333	Ariz.	———	Not known	1.21	0.85	1.42	0.36	30
334	Ariz.	———	Not known	0.76	0.52	1.46	0.24	32
335	Ariz.	———	Not known	1.76	1.44	1.22	0.32	18
336	Colo.	———	Laurel clay	0.37	0.24	1.54	0.13	35
337	Colo.	———	Gilchrist clay loam	0.88	0.79	1.11	0.09	10
338	Colo.	———	——— loamy gravel	6.00	2.32	2.59	3.68	61
339	Colo.	———	Billings clay loam	0.17	0.04	4.25	0.13	76
340	Colo.	———	Fort Collins loam	1.88	1.34	1.40	0.54	29
341	Utah	———	Not classified	0.17	0.04	4.25	0.13	76
342	Utah	———	Jordan loam	0.013	0.006	2.17	0.007	54
343	Utah	———	Taylorsville silty clay loam	0.15	0.05	3.00	0.10	67

344	Utah	———	Mapleton loam	0.88	0.54	1.63	0.34	39
345	Utah	———	Millville loam	0.13	0.04	3.25	0.09	69
346	Wash.	———	Sagemoor fine sandy loam	0.29	0.26	1.12	0.03	10
347	Wash.	———	Sagemoor fine sandy loam	0.59	0.25	2.36	0.34	58
348	Idaho	———	Not known	0.18	0.09	2.00	0.09	50
349	Idaho	———	Not known	0.12	0.05	2.40	0.07	58
350	Idaho	———	Not known	0.94	0.76	1.24	0.18	19
351	Calif.	Tulare	Porterville adobe clay	0.63	0.35	1.80	0.28	44
352	Calif.	Ventura	Altamont loam	0.04	0.007	5.71	0.03	75
353	Calif.	Ventura	Yolo silt loam	0.47	0.29	1.62	0.18	38
354	Calif.	Ventura	Yolo fine sandy loam	1.65	1.28	1.29	0.37	22
355	Calif.	Tulare	San Joaquin loam	0.52	0.27	1.93	0.25	48
356	Calif.	Kern	Hesperia silt loam	1.91	1.06	1.80	0.85	46
357	Calif.	Kern	Hesperia silt loam	1.70	0.85	2.00	0.85	50
358	Calif.	Kern	Arvin fine sandy loam	6.8	4.8	1.42	2.00	34
359	Calif.	Kern	Arvin fine sandy loam	4.7	3.35	1.40	1.35	29
360	Calif.	San Bernardino	Hanford fine sandy loam	1.41	0.98	1.44	0.43	30
361	Calif.	San Bernardino	Ramona loam	0.57	0.31	1.84	0.26	46
362	Calif.	Orange	Hanford fine sandy loam	3.75	3.45	1.09	0.30	8
366	Calif.	Santa Barbara	Yolo silt loam	0.11	0.06	1.83	0.05	45
367	Calif.	Santa Barbara	McCluskey loam	0.67	0.58	1.16	0.09	13
368	Calif.	Monterey	Salinas clay	0.25	0.22	1.14	0.03	12
369	Calif.	Monterey	Salinas clay	0.41	0.29	1.41	0.12	29
Averages				1.205	0.715	1.68	0.49	41

TABLE 3.—*Effect of sodium nitrate application on permeability of a Washington soil.*

Source of sample	Permeability, inches per hour	
	Soil as received	With application of 1,000 lbs. of $NaNO_3$/acre
Washington Fruit Exp. Station:		
(a) Check plot	0.89	0.55
(b) Sodium nitrate plot, 4–7 pounds per tree per year for 12 years, 54 trees per acre	0.15	0.14
Washington Irrigation Station:		
(a) Check plot	0.59	0.25
(b) Sodium nitrate plot, 3,190 pounds per acre total applied for period 1927–36, inclusive	0.29	0.26

The ammonium salts added to the soil samples contained an amount of nitrogen equal to that added as sodium nitrate in the other tests reported. Some of the results obtained are given in Table 4.

TABLE 4.—*A comparison of the effects of ammonium nitrate, ammonium sulfate, and sodium nitrate on soil permeability.*

Soil No.	Permeability, inches per hour			
	Not treated	Ammonium nitrate	Ammonium sulfate	Sodium nitrate
319	0.12	—	0.15	0.03
339	0.17	0.08	0.06	0.04
347	0.59	0.55	0.49	0.25
351	0.63	—	0.79	0.35
352	0.04	0.02	—	0.007
358	6.8	5.6	6.1	4.8
366	0.11	0.08	—	0.06
367	0.67	0.63	—	0.58

The data indicate, in general, that while both ammonium nitrate and ammonium sulfate lower soil permeability, the decrease is much less than with sodium nitrate. Ammonium sulfate did not reduce the permeability of the soils tested as much as noted by Huberty and Pillsbury (10) in a field trial. However, their results on that particular soil (Hesperia sandy loam) have been corroborated in this laboratory.[4]

ZONE OF MINIMUM PERMEABILITY

Hydraulic head measurements were made at half-inch intervals in some of the soil columns by means of manometer tubes inserted into the soil sample through the walls of the permeameter. In this way, a study was made of the location and development in the test samples of the layer of minimum permeability, which usually developed as a result of the fertilizer applications. The layer of minimum

[4]Samples kindly furnished by Huberty and Pillsbury from their field plots.

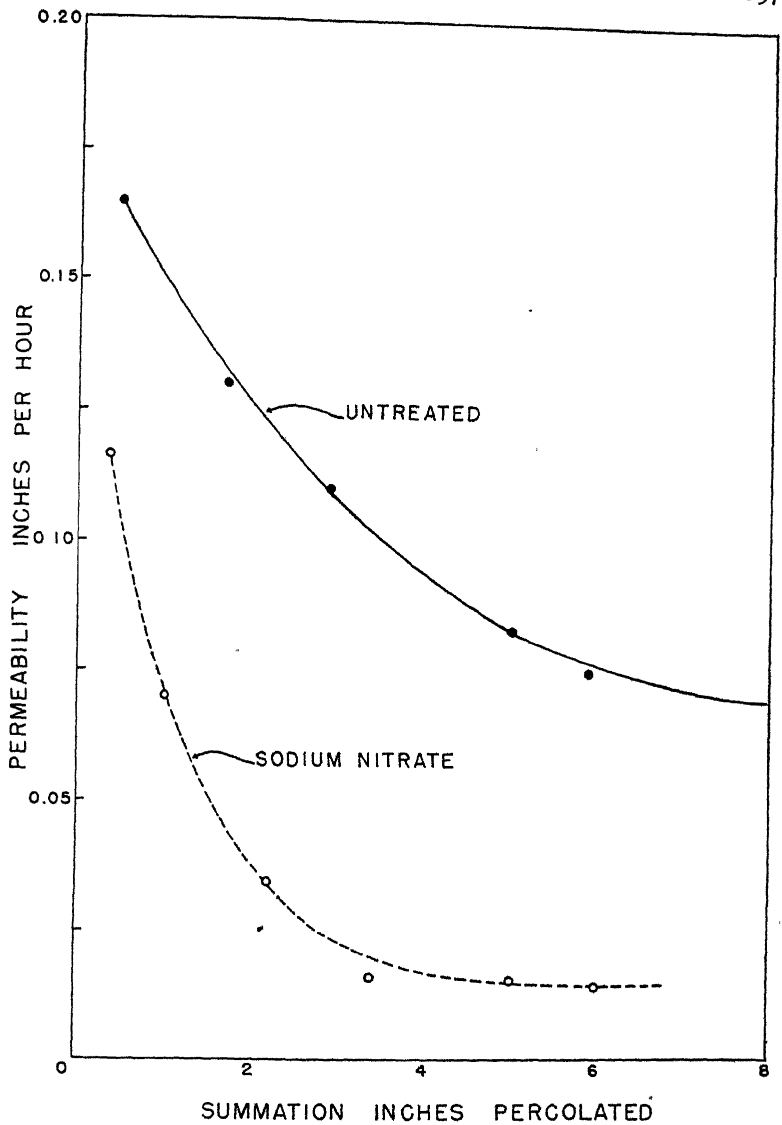

FIG. 2.—Effect of sodium nitrate on permeability of soil No. 320.

permeability, which developed rapidly, corresponded to the region of fertilizer placement whether the fertilizer was applied in the irrigation water, was broadcast on the soil surface, or was stirred into the soil. The thickness of this least permeable layer varied from a few millimeters to about an inch, depending upon manner of fertilizer application. Where no fertilizer applications were made, the permeability was relatively uniform throughout the soil sample.

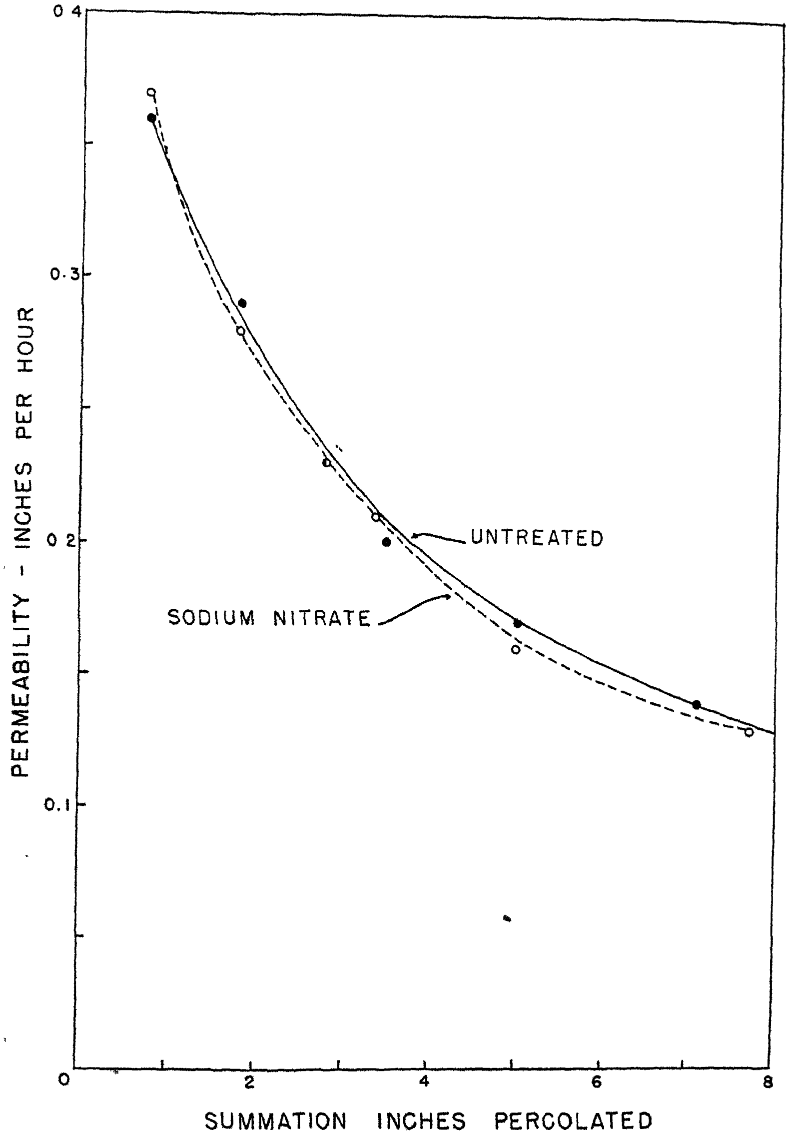

FIG. 3.—Effect of sodium nitrate on permeability of soil No. 327.

EXCHANGEABLE SODIUM

The quantity of sodium adsorbed by the exchange complex of several of the soils, both treated and untreated, was determined when (a) ½ inch, and (b) 12 inches of irrigation water had percolated into the soil. The adsorbed sodium of the untreated soils was low in all

cases, amounting to less than 5% of the exchange capacity of the soil, and percolation of normal irrigation water either did not change the amount of adsorbed sodium or lowered it slightly. The adsorbed sodium of the samples to which 1,000 pounds per acre of sodium nitrate had been added increased greatly upon the addition of ½ inch of irrigation water, rising to as much as 30% of the exchange capacity of the soil in the zone of fertilizer placement. Upon the passage of an additional 11.5 inches of irrigation water through such samples, the percentage of adsorbed sodium held by the soil decreased until it was no greater than that of the untreated soil. Despite this fact, permeability continued to decrease as long as percolation continued, as illustrated in Figs. 1 and 2.

HYDROMETER ANALYSES

At the conclusion of the percolation tests, samples of the soils analyzed for adsorbed sodium were subjected to a modified hydrometer analysis technic to obtain an estimate of the proportion of each size separate which was already dispersed or was easily dispersed. Samples of the wet soils were transferred to liter graduates and made up to volume with distilled water. No dispersing agents were added, and the suspensions were stirred with 15 complete (up and down) steady, slow, vertical strokes with a plunger, and the suspended matter determined with an accurately calibrated specific gravity hydrometer. The readings obtained were corrected for temperature and for the soluble salt content of the suspension. In every case, a greater percentage of soil particles remained in suspension (at every time interval from half an hour to 48 hours) in the samples treated with sodium nitrate than in the untreated samples. There was no significant difference in percentage of soil in suspension after half an inch as compared with 12 inches of percolation in (a) the untreated samples, or (b) the zone of fertilizer placement of the treated samples.

CALCIUM CARBONATE

A majority of the soils of the West contain calcium carbonate in some portion of the profile, but only about half the samples reported herein contained appreciable amounts. The presence of large amounts of calcium carbonate in the soil apparently did not affect the magnitude of the decrease in permeability brought about by the addition of sodium nitrate, although this particular aspect of the problem was not examined systematically.

DISCUSSION

The results obtained indicate that the permeability of many western soils is markedly reduced by sodium nitrate applied at the rate of 1,000 pounds per acre. This is in agreement with the field experiments of Hall (7), Huberty and Pillsbury (10), and others, and conforms to expectations based on a general knowledge of the reactions involved.

All the evidence obtained supports the premise that reduction in permeability following applications of sodium nitrate is due to in-

creased dispersion of the finer fractions of the soil. This is borne out by hydrometer analyses and by the fact that the zone of fertilizer placement remains the impermeable zone despite the *absence of an enduring increase* in exchangeable sodium as a result of the fertilizer application. The contention that sodium does not accumulate to any great extent in leached soil despite heavy applications of sodium nitrate is supported by the data of Schollenberger and Dreilbelbis (12), and others.

The curves in Fig. 1 show that no significant change in permeability occurs unless sodium nitrate is present in the irrigation water in high concentration. The ratio in the soil solution of sodium to other bases must be high, and the actual concentration of sodium must also be high before the sodium content of the base exchange complex can be increased appreciably. Such conditions exist, locally at least, in some sodium nitrate applications. For example, if sodium nitrate is broadcast at the rate of 1,000 pounds per acre, and is dissolved in the first ½ inch of irrigation water, the instantaneous sodium nitrate concentration is almost 10,000 p.p.m. If the original soil solution and irrigation water have a combined salt concentration of as much as 1,000 p.p.m., then upon the addition of the above 10,000 p.p.m. of sodium nitrate the percentage of sodium salts in the soil solution, temporarily, at least, must approximate 90%. Under such conditions, appreciable amounts of sodium are adsorbed by the exchange complex of the soil, and chemical analysis showed that such was the case in this study.

Although heretofore it has not been sufficiently emphasized, most soils remain moderately permeable when leached with high-sodium water as long as the salt content remains fairly high, because the salt tends to keep the soils flocculated. But, as is usually the case, if the high-sodium water is followed by a water of considerably lower salt concentration, i.e., ordinary irrigation water or rainfall, the soil will disperse and become relatively impermeable regardless of the chemical composition of the latter irrigation water (3). This is borne out by the work of Hissink (9) and Gardner (6), among others, who demonstrated that so-called reclamation must involve physical as well as chemical changes. Especially is it important that the soil be allowed to dry if favorable physical changes are to take place to any extent.

Ammonium nitrate and ammonium sulfate in high concentration tend to decrease permeability, but to a considerably lesser degree than sodium nitrate. The results, again, conform to expectations based upon a knowledge of the efficiency of ammonium salts as soil dispersants.

The fact that sodium fertilizers may decrease permeability is not new. The quantitative estimate of the decrease in permeability which can be brought about by high-sodium fertilizer applications should but serve to emphasize the necessity for sound practices. Many agronomists have long advocated applying soluble inorganic fertilizers to the irrigation waters of the West in several small applications, rather than in one large application. Such a procedure is

theoretically sound and tends to preserve good structure and maintain satisfactory infiltration rates.

SUMMARY

Laboratory permeability studies were conducted upon 51 soils representative of the irrigated regions of the West. The water applied to each of these soils was of the same chemical composition as the normal irrigation water used in the field.

When sodium nitrate was added to the soil in concentrations such as are applied in bands in truck crop fertilization, permeability rates were reduced an average of 41%, and in some cases as much as 86%. The reduction was serious in about one-half the soils. Differential permeability studies, hydrometer analyses, and base exchange studies indicate that the decreased permeability is due to increased dispersion of the finer fractions of the soil in the zone of fertilizer placement, rather than to an increase in exchangeable sodium.

The same amount of sodium nitrate applied in the irrigation water in small increments had little effect on soil permeability, hence it is suggested that this fertilizer be applied in such a way that its concentration in irrigation water or soil solution is kept to a minimum.

Ammonium nitrate and ammonium sulfate in high concentration tend to decrease permeability, but to a considerably lesser degree than sodium nitrate.

LITERATURE CITED

1. ALDRICH, D. G., CHAPMAN, H. D., and PARKER, E. R. Ammonium sulfate and sodium nitrate as fertilizers for citrus. Calif. Citro., 30:38. 1944.
2. BROWN, B. E. Concerning some effects of long continued use of sodium nitrate and ammonium sulfate on the soil. Penn. Agr. Exp. Sta. Ann. Rpt., 1908. 84. 1909.
3. FIREMAN, MILTON. Effect of saline irrigation waters upon the permeability and base status of soils. Doctoral Thesis, Univ. of Calif., Berkeley. 1943.
4. ————. Permeability measurements on disturbed soil samples. Soil Sci., 58:337–353. 1944.
5. GANS, R. Zeolithe und ahnliche Verbindungen, ihre Konstitution und Bedeutung für Technik und Landwirtschaft. Jahrb. K. Preuss. Geol. Landesanst. u. Bergakad., 26:179–211. 1905.
6. GARDNER, ROBERT. Some soil properties related to sodium salt problems in irrigated soils. U.S.D.A. Circ. ——. 1945.
7. HALL, A. D. The effect of the long continued use of sodium nitrate on the constitution of the soil. Trans. Chem. Soc. (London), 85:950. 1904.
8. HARDON, H. J. Een onderzoek naar varanderingen van den grond bij voortgezette demesting met chilisalpeter en met zwavelzure ammoniak. Dept. Econ. Zahen. Mededeel. Algemeen. Proefsta. Landbouw., 35:1–13. 1939.
9. HISSINK, D. J. The reclamation of the Dutch saline soils (Solonchak) and their further weathering under the humid climatic conditions of Holland. Soil Sci., 45:83–94. 1938.
10. HUBERTY, M. R., and A. F. PILLSBURY. Factors influencing infiltration-rates into some California soils. Amer. Geophys. Union Trans., 22:686–697. 1941.
11. KELLEY, W. P., and E. E. THOMAS. The effects of alkali on citrus trees. Calif. Agr. Exp. Sta. Bul. 318. 1920.
12. SCHOLLENBERGER, C. J., and F. R. DREILBELBIS. Cropping with various fertilizers, manure and lime treatments upon the exchangeable bases of plot soils. Soil Sci., 29:371–394. 1930.
13. SNEDECOR, G. W. Statistical Methods. Ames, Iowa: College Press, Inc. 1938.

AN EVALUATION OF KRAFT AND PARCHMENT PAPER BAGS FOR THE CONTROL OF POLLINATION IN GRASSES[1]

WESLEY KELLER[2]

ONE of the striking characteristics of present-day grass breeding is the lack of standardized technic. This is clearly reflected in the variety of materials used and methods employed for the control of pollination. Most programs have included selfing studies, if only to determine the mode of reproduction or the extent of self sterility. Now that some of these basic facts have been determined for most of the promising species, selfing will probably be of greatest value in those programs where it is used as a method of breeding, for the ultimate production of hybrids, or in connection with genetic studies. The value of the latter has been emphasized by Mangelsdorf (29)[3] and Hayes (16). Whether the selfing method will be effective in the production of superior hybrids, remains to be seen.

Valle (45) declared that the adoption of a selfing procedure had greatly retarded the breeding of timothy, *Phleum pratense* L., in Finland, and that direct hybridization of selected plants, without any selfing, was much more effective. Tysdal, *et al.* (43) have advocated a similar procedure for alfalfa improvement. Thus, even though selfing should be of restricted usefulness in future grass breeding, it appears that the use of bags for the control of pollination may actually increase.

The present paper reports the results of a study comparing kraft and parchment papers for the self pollination of smooth bromegrass, *Bromus inermis* Leyss.

REVIEW OF LITERATURE

That portion of the literature which is adaptable to tabular classification is summarized in Table 1. Since the results of the thorough investigation of Jenkin (20) have become generally available, the use of cloth isolators has been largely discontinued. Paper cages and waxed cylinders have generally given poor results. Knoll (24) obtained higher seed yields under parchment bags than from oil paper or paramarin.[4] In studies on *Bromus inermis*, Kirk (23) obtained no seeds from isolations under parchment, glassine, or ordinary grocery bags, and Waldron (47) obtained no seeds under either cloth or paper isolators. Smith (39) believed parchment was generally superior to kraft or glassine, but his data were not altogether consistent, and he concluded that differences in seed set under different kinds of paper bags were generally insignificant. Fruwirth (13) found that cutting plants

[1]Contribution of the Division of Forage Crops and Diseases, Bureau of Plant Industry, Soils and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture, in cooperation with the Utah Agricultural Experiment Station and the Intermountain Forest and Range Experiment Station, U. S. Forest Service, Ogden, Utah. Received for publication June 9, 1945.

[2]Geneticist, U. S. Dept. of Agriculture, Logan, Utah. The writer wishes to express appreciation to F. V. Owen, Geneticist, Division of Sugar Plant Investigations, U. S. Dept. of Agriculture, who offered many helpful suggestions in the preparation of the manuscript.

[3]Figures in parenthesis refer to "Literature Cited", p. 907.

[4]Paramarin (Knoll-24) is a coarse, strong paper, of dark, orange-red color, impregnated with waxy materials. Oil paper is a paper saturated with oil, of yellow color, drawn out over wide meshed gauze for strength. Both paramarin and oil paper are impervious to water and water vapor.

TABLE I.—*Summary of methods reported in the literature for isolation, support of isolator, and the basis for reporting results obtained in selfing studies, the numbers refering to Literature Cited, page 907.*

Method of isolation									
Cloth cages, tents, bags, ballons or cylinders	Paper								Seasonal or distance
	Cages	Sleeves, balloons, hose, or cylinders	Bags*						
			Parchment	Kraft	Glassine	Oil	Glazed	Paramarin	
1, 4, 11, 20, 22, 25, 28, 36, 40, 42, 47, 51	13, 24, 36	1, 2, 5, 14, 20, 24, 26, 27, 36, 40, 48	11, 19, 20, 23, 24, 30, 31, 37, 38, 39, 41, 42, 44	6, 8, 17, 18, 21, 23, 29, 49, 51	12, 13, 15, 17, 23, 32, 33, 34, 36, 39, 50	24, 36	17, 20	24	5, 13, 17

Method of support				
Cages	Sleeves, balloons, hose	Paper bags		
Investigators all used wood frames	Tied top and bottom over a stout stake, except Knoll (24)†	Tied at mouth to a stake	Tied at mouth to a stake, at bottom from eyelet to stake	Placed over wire stake, closed with paper clips
		18, 25, 33, 39	19, 30, 31‡	6, 8, 21§

Basis for reporting results				
By weight	Seeds per floret	Seeds per 100 spikelets	Seeds per inflorescence	Seeds per centimeter of inflorescence
11, 24, 36, 42	13, 20, 22, 25, 32, 39, 51	6, 20, 21	8, 18, 19, 20, 30, 31, 32, 38, 42, 44	20, 32, 46

*In the European literature, "pergament" is parchment, and "pergamin" (or pergamine) is glassine paper.
†Knoll used two stakes outside each isolator. The bottoms of his "hose" were buried in the soil, whereas his "panicle pockets" were closed by tying around the culms.
‡Nilsson (32) tied the bag directly to the stake, both at the mouth and near the bottom. Myers (31) closed the bag around the culms with a wooden tree label.
§Troll (41) placed his bags over a wooden stake, to the top of which he attached a wire spiral to protect the bag during storms. Bags were closed by tying.

back to effect seasonal isolation by retarding their development did not adversely influence the flowering process. Calder (5) placed plants every 5 chains (330 feet) in Algerian oats, but for critical work used parchment balloons. Glazed paper bags (1, 2, 20, 40) and cellophane bags (7, 27) are apparently satisfactory for selfing studies conducted in greenhouses.

The Welsh investigators regularly place cotton around the culms where the bag was to be tied over them. Myers (31) found that this protection did not affect seed set of *Dactylis glomerata*. East (9), working on *Zea mays*, and using ordinary grocery bags, moistened them at the mouth to facilitate close tying around the plant.

The size of bags used has varied greatly, but none of the investigators cited has presented evidence indicating one size is better than another.

Raum (36), Malte (28), Knoll (24), and Beddows (1) drew attention to the unfavorable influence of a high humidity in the isolator. Knoll obtained a negative correlation between air humidity within the isolator and seed set. He obtained the lowest humidity and the highest seed set with parchment paper (in comparison with paramarin and oil paper).

Gregor and Sansome (15) concluded that the isolation bags were not responsible for sterility since plants found to be self-sterile under bags were likewise self-sterile when isolated by time of flowering. Nilsson (32), on the basis of statistical studies, concluded that the bag had only a small influence on seed set. Clark (6) reached a similar conclusion since many highly self-fertile plants had been isolated under bags.

Brewbaker (3) compared several papers for selfing sugar beets. Best results were obtained from large parchment bags, and the poorest from small parchment bags. Unfortunately, his large bags were of 30-pound and his small of 40-pound paper. He found that the humidity was higher and the temperature lower in parchment and cellophane than in kraft and hemp bags. Pearson (35) found the highest temperature in cellophane bags followed by glassine, bond, and manila with the lowest temperature in muslin bags.

MATERIALS AND METHODS

Two groups of plants of *Bromus inermis* were used for the present study. The first group, bagged only in 1943, consisted of five plants selected for rather high self-fertility as determined from previous bagging. All plants were derived from a common ancestor, one by open pollination, two by selfing one generation, and two by selfing two generations. They were expected to indicate the potentialities of the different papers on material capable of considerable self-fertility.

The second group consisted of two families of plants which may be regarded as unselected, but in each of which previous bagging had revealed considerable variation in self-fertility. During 1943, 25 plants of an S_1 family and 6 plants of an S_2 family were bagged. In 1944, 21 plants of the S_1 family and 6 plants of the S_2 family were again bagged. Nineteen plants of the S_1 family and 6 from the S_2 family, a total of 25 plants, were bagged in both 1943 and 1944.

The present study was undertaken to compare brown kraft bags, commonly used at this station, with bags of the same size made of parchment and bleached kraft[5] paper. War restrictions on paper made it impossible to obtain either bleached kraft or parchment in 40-pound material, but a 50-pound bleached kraft was obtained.[6] Both 35-pound, and 43-pound parchment papers were obtained on the market. The necessary bags of each of these papers were made up by hand, using waterproof glue. During the 1944 season, bags of 27-pound parchment were also used.

All bags were 3×26 inches and were supported in the field by wire stakes and closed with gem paper clips. Before any bags were put on the plants, proper identification numbers were stamped on them. All of the different types of paper bags used each season were placed on each plant used for the study. All of the

[5]Bleached kraft paper was suggested to the writer by F. V. Owen, geneticist, U. S. Dept. of Agriculture.

[6]The writer wishes to acknowledge the generous cooperation of the St. Helen's Pulp and Paper Company, St. Helens, Ore., who contributed the bleached kraft paper after it could no longer be obtained from distributors.

bagging work was done in a few days, and was completed a few days prior to anthesis.

After the flowering season was over, and the seeds on exposed panicles had hardened, but without evidence of shattering, the bagged material was harvested and allowed to dry thoroughly. Each bag was then opened, the contents carefully removed, the number of spikelets on each panicle was counted, and the seeds in each bag threshed by hand. A partial separation of seed and chaff was accomplished by dropping the threshed mass in front of a wire screen against which an air current from an electric fan was directed. The number of seeds was then counted. In 1944 the seed yield of each panicle was determined separately.

All of the data obtained have been analyzed by the variance method. Germination percentages were taken through the angular transformation to degrees, to avoid possible bias. Fisher and Yates (10), Table 12 was used for this transformation.

EXPERIMENTAL RESULTS

A summary of all data relevant to the evaluation of the different papers is presented in Table 2. Investigations during 1943 (parts A and B) reveal that the types of papers used led to significantly different results in selfed seeds produced per 100 spikelets bagged, weight of seeds, germination, and viable seeds per 100 spikelets bagged. These data reveal the superiority of 35-pound parchment over the other papers, with 50-pound bleached kraft the second best paper. The superiority of 35-pound parchment relates to the greater number of selfed seeds produced by panicles that were isolated by it. These seeds were heavy, and gave satisfactory germination values. Panicles isolated by 50-pound bleached kraft yielded fewer seeds, but they were also heavy and gave satisfactory germination values. Panicles isolated by 40-pound brown kraft and 43-pound parchment yielded either fewer seeds or seeds of lighter weight, or both fewer and lighter seeds. Germination values are significantly influenced by weight of seeds. The data of Table 2, part A, gave a highly significant correlation coefficient of $+.560$ for weight$\times$germination.

The data presented in Table 2, part C (1944), indicate that 27-pound parchment and 35-pound parchment are of approximately equal value. However, since the lighter paper yielded heavier seeds, some advantage might be claimed for it.

DISCUSSION

One of the significant differences revealed by the present study is that between 35-pound and 43-pound parchment papers. The lighter weight paper was superior to the heavier in every respect. Bleached kraft was also consistently superior to brown kraft.

Some of the characteristics of the different papers used were examined in seeking an explanation for their relative efficiencies. The data are presented in Table 3. Diffusion of light was measured with a Weston foot candle meter and is expressed in percentage of total light. Kraft papers allowed penetration of only approximately one-third as much of the total light as passed through parchment papers. There is obviously no relation between total light entering the bag and selfed seed set. It is noteworthy that the heaviest parchment allowed as much light penetration as the lighter weights. This suggests a qualitative difference in these papers.

An attempt was made under field conditions to measure the porosity of the papers by determining the amount of water evaporated from a vial placed under each bag during an extended period of time. The data obtained do not reveal any striking differences. They are subject to a number of unknown variables and cannot be taken too literally.

Under low differential air pressures 43-pound parchment was found to be impervious, whereas all other papers allowed air penetration. This represents a clear-cut difference between 43-pound parchment

TABLE 2.—*Summary of selfing with selected and unselected plants of Bromus inermis in which kraft and parchment papers are evaluated, with four panicles placed in each bag.*

Paper	Number of panicles studied	Mean No. spikelets per panicle	Selfed seeds per 100 spikelets	Weight of 100 seeds in milligrams	Germination in degrees	Viable seeds per 100 spikelets bagged
			A, Five Selected Plants (1943)			
Kraft:						
40-lb. brown	100	69.5	112.2	171.4	69.8	100.4
50-lb. bleached	100	77.0	118.3	221.5	75.3	128.6
Parchment:						
35-lb	100	74.2	162.2	195.8	73.0	147.4
43-lb	100	67.0	118.1	124.7	56.4	91.0
Sig. diff., 5% level	—	—	21.5	13.1	5.24	22.5
F values						
Calculated	—	1.74	8.8	77.5	20.7	10.5
Required at 5% level	—	2.64	2.72	2.72	2.72	2.72
			B, 31 Unselected Plants (1943)*			
Kraft						
40-lb. brown	124	54.3	25.7	136.6	46.6	17.8
50-lb. bleached	124	58.5	40.3	185.2	57.3	41.9
Parchment						
35-lb	124	54.8	67.3	199.9	60.6	72.2
43-lb	124	50.3	39.7	97.2	30.3	14.3
Sig. diff., 5% level	—	—	11.6	26.4	5.5	17.3
F values						
Calculated	—	0.76	17.67	26.3	50.8	19.8
Required at 5% level	—	2.71	2.71	2.90	2.90	2.90
			C, 33 Unselected Plants (1944)*			
Parchment						
27-lb	396	46.2	35.0	176.4	65.6	41.8
35-lb	396	48.0	31.9	161.9	65.3	39.5
F values						
Calculated	—	1.62	1.7	22.4	0.03	0.43
Required at 5% level	—	3.92	3.92	4.04	4.04	4.04

*Only 12 plants yielded sufficient seeds to contribute information on weight, germination, and viable seeds per 100 spikelets bagged.

and the other papers, but it is of doubtful significance because no attempt was made to seal the bag where it was closed around the culms and supporting wire. Thus, any type of differential set up within the bag, such as the accumulation of CO_2, would not be entirely dependent upon diffusion through the paper directly to escape from the bag. It would seem, therefore, that none of the characteristics of the different papers, as represented in Table 3, would be adequate to account for their differential values as represented by the data of Table 2.

TABLE 3.—*Characteristics of the different papers as determined by measurements of the penetration of light, air, and water vapor.*

	Kraft		Parchment		
	40-lb. brown	50-lb. bleached	27-lb.	35-lb.	43-lb.
Light, % of total*	15.8	17.4	52.5	51.0	56.5
Water evaporation†	63.5	54.5	—	52.5	48.5
Air penetration‡	0.38	0.11	0.06	0.047	0.00

*Mean of 12 samples with total light intensity varying from 600 to 9,300 foot candles.
†Amount of water in grams evaporated from a vial supported in each type of bag. Means of two determinations; duration 40 days under field conditions.
‡Cubic centimeters per second through a disc 102 square centimeters in size when under a relatively constant pressure differential of 1 mm.

SUMMARY

More selfed seeds were produced by *Bromus inermis* under bags of 35-pound parchment paper than from 50-pound bleached kraft, 43-pound parchment, or 40-pound brown kraft.

Fifty-pound bleached kraft was superior to 43-pound parchment and 40-pound brown kraft.

In another season 35-pound parchment and 27-pound parchment appeared to be of approximately equal value.

Seeds produced under 35-pound parchment and 50-pound bleached kraft were heavier than those from 40-pound brown kraft and 43-pound parchment. There was a significant relationship between weight of seeds and their ability to germinate.

Measurements of penetration of light and air through the different papers, and of evaporation of water from vials in the bags, failed to reveal any characteristics which might account for the results obtained.

LITERATURE CITED

1. BEDDOWS, A. R. Seed setting and flowering in various grasses. Welsh Plant Breeding Sta., Aberystwyth (Bul.), Ser. H., No. 12, 5–99. 1931.
2. ————, and DAVIS, A. G. Illustrated notes on the technique of grass breeding at Aberystwyth. Imp. Bur. Pastures and Forage Crops: Herbage Rev., 6:221–227. 1938.
3. BREWBAKER, H. E. Self fertilization in sugar beets as influenced by type of isolator and other factors. Jour. Agr. Res., 48:323–337. 1934.
4. BURNS, W., and BARVE, D. B. Further contributions on the technique employed in the breeding of herbage and forage plants. IV Breeding Technique for *Pennisetum typhoideum*. Imp. Bur. Plant Gen., Herbage Plants, Bul. 7: 21–23. 1932.

5. CALDER, J. W. Technique employed in grassland research in New Zealand: IV Methods employed in the breeding of pasture plants. Imp. Bur. Plant Gen.; Herbage Pub. Ser. Bul. 11:36–39. 1933.
6. CLARK, JOHN W. The effect of some environmental influences in bulk hybridization of grass. Jour. Amer. Soc. Agron., 36:132–140. 1944.
7. CORKILL, L. Inheritance of fluorescence in rye-grass. Nature, 130: 134. 1932.
8. DOMINGO, WAYNE E. Bulk emasculation and pollination of smooth bromegrass, *Bromus inermis*. Jour. Amer. Soc. Agron., 33:993–1002. 1941.
9. EAST, EDWARD M. The relation of certain biological principles to plant breeding. Conn. Agr. Exp. Sta. Bul. 158. 5–93. 1907.
10. FISHER, R. A., and YATES, F. Statistical tables for biological, agricultural and medical research. London: Oliver & Boyd. 1938.
11. FRANDSEN, H. N. Die befruchtungsverhältnisse bei Gras und Klee in ihrer beziehung zur Züchtung. Ztschr. f. Pflanzenzucht., 5:1–30. 1917.
12. ————. The breeding of herbage plants in Scandinavia and Finland: Denmark. Imp. Agr. Bur. Joint Pub. No. 3. 1940.
13. FRUWIRTH, C. Beitrage zu den Grundlagen der Züchtung einiger landwirtschaftlicher Kulturpflanzen. V. Graser. Naturw. Ztschr. f. Forst-u. Landw., 14:127–149. 1916.
14. GOVAERT, R. Zaadzetting na zalfbestuiving bij grassen. Mededeelingen der Landbouwhoogeschool en der Opzoekingsststions van den Staat Ti Gent., 4:(3) 155–167. 1936.
15. GREGOR, J. W., and SANSOME, F. W. Experiments on the genetics of wild populations, Part I. Grasses. Jour. Gen., 17:349–364. 1926.
16. HAYES, H. K. Green pastures for the plant breeder. Jour. Amer. Soc. Agron., 27:957–962. 1935.
17. ————, and BARKER, H. D. The effects of self-fertilization in timothy. Jour. Amer. Soc. Agron., 14:289–293. 1922.
18. ———— and CLARKE, S. E. Selection in self-fertilized lines as a means of improving timothy. Sci. Agr., 5: p. 313–317. 1925.
19. ———— and SCHMID, A. R. Selection in self-pollinated lines of *Bromus inermis* Leyss; *Festuca elatior* L, and *Dactylis glomerata* L. Jour. Amer. Soc. Agron., 35:934–943. 1943.
20. JENKIN, T. J. The method and technique of selection, breeding and strain-building in grasses. Imp. Bur. Plant Gen., Herbage Plants, Bul. 3:5–34. 1931.
21. KELLER, W. The bulk hybridization of smooth bromegrass. Jour. Her., 35: 49–56. 1944.
22. KIRK, L. E. Self-fertilization in relation to forage crop improvement. Sci. Agr., 8:1–40. 1927.
23. ————. Methods employed in the breeding of biennial sweet clover (*Melilotus*) and brief notes on the breeding of Lucerne (*Medicago sativa*), brome grass (*Bromus inermis*) and slender wheat grass (*Agropyron tenerum*). Imp. Bur. Plant Gen., Herbage Plants, Bul. 7:5–13. 1932.
24. KNOLL, J. Untersuchungen über den Einfluss der künstlichen Isolierung auf die Fruchtbarkeitsverhältnisse bei *Phleum pratense*, *Avena elatior* und einigen anderen Gras Arten. Wis. Arch. f. Landw., Abt. A., Arch. F. Pflanzenbau, 2:318–364. 1929.
25. KNOWLES, R. P., and HORNER, W. H. Methods of selfing and crossing crested wheatgrass. Sci. Agr., 23:598–612. 1943.
26. LAW, ALVIN G., and ANDERSON, KLING L. The effect of selection and inbreeding on the growth of big bluestem (*Andropogon furcatus*, Muhl.) Jour. Amer. Soc. Agron., 32:931–943. 1940.
27. LEVY, E. BRUCE. Technique employed in grassland research in New Zealand: I. Strain testing and strain building. Imp. Bur. Plant Gen., Herbage Pub. Ser. Bul. 11:6–16. 1933.
28. MALTE, M. O. Breeding methods in forage plants. Sci. Agr., 1:25–29. 1921.
29. MANGELSDORF, P. C. Progress and possibilities in forage crop improvement. Jour. Amer. Soc. Agron., 19:329–342. 1927.
30. MURPHY, R. P. Methods of breeding crested wheatgrass, *Agropyron eristatum* (L.) Beauv. Jour. Amer. Soc. Agron., 34:553–565. 1942.

31. MYERS, W. M. Analysis of non-heritable variations in seed set under bag among plants of orchard grass. *Dactylis glomerata* L. Jour. Amer. Soc. Agron., 34:1114–1124. 1942.
32. NILSSON, F. Studies in fertility and inbreeding in some herbage grasses. Hereditas, 19:1–162. 1934.
33. NILSSON-LEISSNER, G. A preliminary inbreeding experiment in red fescue (*Festuca rubra*). Herediatas, 18:115–121. 1933.
34. ———— and NILSSON, FR. The breeding of herbage plants in Scandinavia and Finland: Herbage plant breeding in Sweden. Imp. Agr. Bur., Joint Pub. No. 3. 1940.
35. PEARSON, O. H. Influence of materials and colors upon plant temperatures within bags. Proc. Amer. Soc. Hort. Sci., 30:501–506. 1934.
36. RAUM, H. Einige praktische Winke für die Gräserzüchtung. Ztschr. f. Pflanzenzucht., 2:39–50. 1914.
37. ROGLER, G. A. Russian wild-rye, *Elymus junceus* Fisch. Jour. Amer. Soc. Agron., 33:266–268. 1941.
38. SCHULTZ, H. K. A study of methods of breeding orchard grass (*Dactylis glomerata* L.) Jour. Amer. Soc. Agron., 33:546–558. 1941.
39. SMITH, D. C. Pollination and seed formation in grasses. Jour. Agr. Res., 68: 79–95. 1944.
40. STAPLEDON, R. G., JENKINS, T. J., and WILLIAMS, R. D. Preliminary Investigations with herbage plants: Problems connected with the fertilization of the grasses and clovers. Welsh Plant Breeding Station, Aberystwyth, (Bul.) Ser. H., No. 1, 16–21. 1922.
41. TROLL, H. J. Untersuchungen über Selbststerilität und Selbstfertilität bei Grasern. Ztschr. f. Zücht. Reihe A, Pflanzenzucht., 16:105–136. 1931.
42. TRUMBLE, H. C. Further contributions on the technique employed in the breeding of herbage and forage plants. III—The improvement of *Phalaris* species by selective breeding. Imp. Bur. of Plant Gen., Herbage Plants, Bul. 7:17–20. 1932.
43. TYSDAL, H. M., KIESSELBACH, T. A., and WESTOVER, H. L. Alfalfa breeding. Neb. Agr. Exp. Sta. Res. Bul. 124:1–46. 1942.
44. VALLE, OTTO. (The use of the Tammisto bag in grass breeding.) Jour. Sci. Agr. Soc. Finland, 5:13–44. 1933. (From Herbage Abs., 3:79).
45. ————. Herbage plant improvement in Finland. Herbage Reviews, 6, No. 4:263–270. 1938.
46. VINOGRADOVA, N. M. (The technique of breeding perennial grasses.) Reg. Exp. Sta. Agronomy, Moscow, Bul. 7:3–26. 1935.
47. WALDRON, L. R. Some physical and chemical studies of certain clones and sibs of brome grass. N. D. Agr. Exp. Sta. Bul. 152 (Res. Bul. 1). 1921.
48. WALLER, ADOLPH, and THATCHER, L. E. Improved technique in preventing access of stray pollen. Jour. Amer. Soc. Agron., 9:191–195. 1917.
49. WEBBER, H. J., *et al.* The production of new and improved varieties of timothy. Cornell Univ. Agr. Exp. Sta. Bul. 313. 1912.
50. WEXELSEN, H. Chlorophyll-deficient seedlings in timothy (*Phleum pratense* L.) Jour. Her., 32:227–231. 1941.
51. WOLFE, T. K., and KIPPS, M. S. Pollination studies with orchard grass. Jour. Amer. Soc. Agron., Jour., 17:748–752. 1925.

INVESTIGATIONS WITH THE CASTOR-BEAN PLANT: III. FERTILIZERS, CLIPPING, METHOD OF PLANTING, AND TIME OF HARVEST[1]

W. E. DOMINGO AND D. M. CROOKS[2]

SEVERAL cultural methods other than rate and date of planting castor beans were studied cooperatively from 1941 to 1943[3] by the Bureau of Plant Industry, Soils, and Agricultural Engineering and state agricultural experiment stations. Among them were the use of fertilizers, the method of planting, the clipping or pruning of the growing point, and the time of harvest. Although these tests were conducted on a less extensive scale than the rate- and date-of-planting tests, the results were useful in making recommendations.

FERTILIZERS

Eight fertilizer tests were conducted, six in 1941 and two in 1943. The 1941 tests were located at Maple Hill and Parsons, Kans.; Arapaho and Stillwater, Okla.; Poplarville, Miss.; and Columbia, Mo. Five of the tests compared fertilizers applied to the Conner variety, while the Poplarville test compared fertilizer placements on the Scott variety (probably a selection from U. S. 4). The work was initiated late in the planting season of 1941, and the tests necessarily lacked uniformity in design and fertilizers used. The treatments and yields are listed in Table 1. In view of the usual magnitude of the difference necessary for significance in castor bean tests which are designed to permit statistical analysis, the yield differences between treatments in these tests are not believed to be sufficiently large to be considered significant. Thus, the 1941 data indicate that a profitable response would likely not result from application of fertilizers to castor beans, either before planting or as a side dressing after emergence.

The two fertilizer tests in 1943 were conducted at Lexington and Princeton, Ky. In these tests, which were of uniform design, only the Conner variety was used and nitrogen, phosphorus, and potassium were each applied alone and in all possible combinations at the rate of 250 pounds of 4–12–8 per acre. Plots were 4×10 hills in size with single plants spaced 3.5×3.5 feet, and only the center two rows were used for yield data. At Princeton the treatments were in quadruplicate and at Lexington they were in duplicate. The yields from these two tests are given in Table 2. The plot at Princeton was rather high in productivity, but it was thought that the fertilizers used in this test would have increased corn yields from 5 to 7% for each

[1]Contribution from the Division of Tobacco, Medicinal, and Special Crops, Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture, Beltsville, Md. Received for publication April 10, 1945. The first of this series appeared on pages 750 to 762 and the second part on pages 812 to 820 of Vol. 37 of this JOURNAL.

[2]Agronomist and Principal Horticulturist in Charge, respectively.

[3]Mimeographed reports D.R.P. 34, 35, and 40 give data in detail and summarize this work annually for 1941, 1942, and 1943, respectively.

TABLE 1.—*Yields of castor beans from six fertilizer tests in 1941.**

Location	Fertilizer	Pounds of fertilizer per acre	Yield, pounds per acre
Maple Hill, Kans.	None	—	558
	Sodium nitrate	—	614
	Superphosphate 20%	135	643
	Mixed	—	569
Parsons, Kans.	None	—	472
	Superphosphate 20%	135	434
	Lime	6,000	385
	Lime and superphosphate 20%	—	392
	Mixed	—	465
Arapaho, Okla.	None	—	155
	Sodium nitrate	—	190
	Superphosphate 20%	135	220
	Mixed	—	164
Stillwater, Okla.	None	—	819
	Ammonium sulfate	72	858
	Superphosphate 20%	135	888
	Mixed	—	885
Poplarville, Miss.	4-8-4 below seed before planting	300	404
	4-8-4 side dressing after emergence	300	303
Columbia, Mo.	None	—	1,001
	0-20-0	150	984
	0-20-10	150	1,141
	0-20-20	150	1,191
	10-20-0	150	1,109
	10-20-10	150	1,141
	10-20-20	150	1,201
	10-20-10 plus 50 lbs. $CaCO_3$	150	1,201
	10-20-10 plus 50 lbs. $MgCO_3$	150	1,127
	5-10-5	150	1,099

*Yields are in pounds of hulled beans, except at Poplarville where yields are in pounds of beans in the hull.

element. As can be seen in the table, only phosphorus when used alone produced a significant increase (8.5%) in yield. This does not constitute a substantial case for phosphorus, but it might suggest that the species is more like corn in its phosphorus requirement than in its nitrogen and potassium requirements. With reference to the Lexington test, it is felt that the fertilizers used would not have produced any increase in corn yields, and Table 2 shows that they produced no significant increases in castor bean yields.

CLIPPING TESTS

Increased branching has been observed in young castor bean plants from which the upper portion of the stem has been removed. It has been suggested that systematic removal of the tops of young plants might encourage branching and that each branch might bear a raceme all of which would mature at the same time and thus reduce

TABLE 2.—*Yields in pounds of hulled beans per acre of the Conner variety in fertilizer tests at two locations in Kentucky in 1943.*

Fertilizer	Location	
	Princeton	Lexington
O	1,235	1,445
N	1,159	1,538
P	1,340*	1,345
K	1,268	1,431
NP	1,292	1,407
NK	1,127	1,564
PK	1,322	1,341
NPK	1,289	1,538

*Significantly greater than yield of plots receiving no fertilizer.

harvesting costs. Tests on this point were conducted at Manhattan, Kans., and Stillwater, Okla., in 1943. At Manhattan the treated plants were clipped just above the fourth, fifth, and sixth nodes as soon as those nodes appeared (June 25 to June 30) which was considered to be the optimum time for such treatment. This test included both Conner and Kentucky 38, and the 4×10 hill plots were in quadruplicate with only the center two rows harvested for yield. At Stillwater treatment was delayed until most of the first racemes were in bloom, when clipping was done just above the fifth, seventh, ninth, eleventh, and thirteenth nodes on July 12. Only Conner was used in this test and the plots were arranged systematically in three replications. The yield data from these tests are given in Table 3.

TABLE 3.—*Yields in pounds of hulled beans per acre of two clipping tests.*

Treatment	Manhattan, Kans.			Stillwater, Okla., Conner
	Conner	Kentucky 38	Average	
Not clipped	1,496*	1,219	1,357*	432*
Clipped above 4th node	914	893	903	—
Clipped above 5th node	1,040	1,032	1,036	222
Clipped above 6th node	826	1,070	948	—
Clipped above 7th node	—	—	—	148
Clipped above 9th node	—	—	—	108
Clipped above 11th node	—	—	—	68
Clipped above 13th node	—	—	—	105

*Differences between this value and all others in the column are highly significant.

Examination of the data on yield and other characteristics failed to show appreciable advantage for the clipping treatment. Yields were materially reduced by clipping at both the early and late stages. Although clipping stimulated branching, the dates of heading and maturity were retarded which contributed greatly to decreased yields. Critical comparisons of uniformity of maturity were prevented by dry weather which caused abnormal ripening.

METHOD OF PLANTING

Since the castor bean is adapted to areas where corn is surface planted and also to areas where it is planted in listed furrows, it was considered desirable to determine whether either method is distinctly preferable for this plant. At Manhattan, Kans., in 1941 and 1942 the Conner variety was hand-planted at the normal depth both in the bottom of listed furrows and on the surface. In 1941 the unreplicated plots were 10×35 hills in size. In 1942 a plot of 14 listed rows, each 35 hills long, was bordered on both sides by nine surface-planted rows of which all except the outer two on each side were used for yield data.

The yields in pounds of hulled beans per acre on the surface-planted and listed plots, respectively, were 795 and 631 in 1942, and 1,040 and 982 in 1943. In view of the limited nature of these tests no definite conclusions can be formulated, although at present it seems that as regards yield alone either method is acceptable and that the method used can be governed by the equipment available. It was observed that weed control was much easier in the listed plot, where in 1943 only two cultivations were necessary as compared with five for the surface-planted plots. Planting in lister furrows probably delays growth somewhat as compared with surface planting since the seed is placed in colder soil. In certain years this factor might adversely affect yields.

TIME OF HARVEST

While the present varieties are markedly resistant to shattering when compared with the strains grown in the 1800's, many growers have considered it necessary to harvest more than once. This makes harvesting the most expensive of production operations. Studies were designed to determine the extent to which the number of harvests could be reduced without serious loss of beans by shattering. The different treatments were (a) harvests as often as necessary to get all of the beans, (b) harvests only when quite serious loss seemed imminent, and (c) only one harvest at the time of the first killing frost.

Three varieties, Conner, Doughty 11, and Kentucky 38, were used in a split-plot design to determine whether all varieties performed alike under the three treatments. Varieties were in the main plots and treatments in the sub-plots, which were 4×10 hills in size. The center two rows of each plot were used for yield data. These tests were conducted at Stillwater, Okla., and Manhattan and Wichita, Kans. Treatments were in quadruplicate at all locations except Wichita where treatments were in duplicate and treatment "b" was omitted.

Data from these tests are presented in Table 4. They show that yields from methods "a" and "b" were essentially the same, but that method "c" reduced yields on all varieties at Manhattan and Wichita and on Kentucky 38 at Stillwater.

TABLE 4.—*Yields in pounds of hulled beans per acre from three time-of-harvest tests involving three varieties of castor beans.**

Location	Conner			Doughty 11			Kentucky 38			Treatment averages					Significance of method × variety interaction
	a	b	c	a	b	c	a	b	c	a	b	c	Least significant difference†		
													5%	1%	
Manhattan, Kans.	1,241	1,132	1,135	1,043	1,226	964	961	947	888	1,082	1,102	996	92	—	No
Wichita, Kans.‡	898	—	611	744	—	755	691	—	454	777	—	606	111	—	No
Stillwater, Okla.	510	473	442	409	432	409	524	543	382	481	483	411	41	56	Yes§

*Treatment a = harvests as often as necessary to get all beans; b = harvests only when serious loss seemed imminent; c = one harvest made at the time of the first killing frost.
†Only where differences were significant.
‡Two replications, and method "b" not included.
§Differences within Conner and Doughty 11 not significant, but Kentucky 38 treatment c significantly lower than treatments a or b.

SUMMARY

1. Eight fertilizer tests in Kansas, Kentucky, Mississippi, Missouri, and Oklahoma failed to show any marked yield increase from nitrogen, phosphorus, or potassium, either alone or in combination, on the Conner variety of castor beans. The only significant increase from any treatment was with phosphorus alone at Princeton, Ky. In the same test phosphorus with nitrogen and potassium produced no such increase.

2. Clipping the stem from young plants above the fourth to the thirteenth nodes in two tests in 1943 increased branching as expected, but yields of treated plants were materially reduced, largely because of delayed maturity.

3. Surface-planted plots yielded somewhat more than listed plots in two small tests in Kansas. The differences, however, were not great and the method used should probably be governed by the equipment available. Weed control was much easier in the listed plots. In certain years planting in cold soil in lister furrows might affect yields adversely.

4. In general, delaying harvest of the three common varieties of castor beans until frost in three tests in 1943 resulted in significant loss of seed by shattering. On the other hand, yields were only slightly different from plots harvested frequently enough to get all of the seed and from plots harvested only when serious loss seemed imminent.

THE INHERITANCE OF THREE GENES THAT INFLUENCE TIME OF FLORAL INITIATION AND MATURITY DATE IN MILO[1]

J. R. QUINBY AND R. E. KARPER[2]

SORGHUM, *Sorghum vulgare*, Pers., although apparently indigenous to tropical Africa is now grown in latitudes as high as 45 degrees. Since sorghum is a short-day plant according to the classification of Garner and Allard (10),[3] which means that maturity is hastened by growing under short photoperiods, the varieties that are adapted to the higher latitudes of long summer days must have arisen at some time in the past as the result of mutation of genes that control response to photoperiod.

Since the duration of the vegetative period in a grass is controlled by the time of floral initiation, a study of the inheritance of maturity in sorghum is actually a study of the inheritance of the genes that influence the biochemical changes that bring about floral initiation. This paper reports on the inheritance of three genes that influence maturity date in milo and which cause profound changes in plant growth.

REVIEW OF LITERATURE

In a plant with a terminal inflorescent like sorghum, duration of the vegetative period and ultimate plant size are dependent upon the time that floral initiation takes place. In a grass, a delay in the initiation of a floral bud results in a larger number of internodes and leaves which brings about a delay in flowering and maturity. There are illustrations and an excellent discussion of the developmental morphology of the growing point in certain grasses by Evans and Grover (9). Sinnott (29) has reported that the size of any organ depends upon the size of the growing point out of which it develops, and Abbe, Randolph, and Einset (1), using *Zea mays*, have shown that the relative size of a leaf is determined at the time the leaf primordium is laid down. These things being true, it follows that the large leaves that appear towards the top of a plant result from the greater circumference of the growing point as it grows older, and stalk diameter is positively correlated with number of nodes and the duration of growth prior to floral initiation. Earliness of maturity is associated with small plant growth and lateness of maturity with large plant growth, but the determining factor in both maturity and ultimate plant size within a species is the duration of the period prior to floral initiation. Sieglinger (28) recognized in sorghum the association between number of leaves and leaf size, diameter and height of stalk, and vigor of plant, and showed that varieties have different numbers of leaves, and that a change in planting date which changes both the photoperiod and temperature brings about differences in leaf number.

Hamner (14, 15), in discussing the biochemical nature of photoperiodism, has assumed that substances of a hormone-like nature must be involved in the differentiation that ultimately leads to flowering. Yarnell (37) has discussed and reviewed the literature that is concerned with the influence of environment on the expression of hereditary factors. It is apparent that the genes which influence growth and differentiation in plants are themselves influenced in expression by

[1]Contribution No. 901 from the Division of Agronomy, Texas Agricultural Experiment Station, College Station, Tex. Published by permission of the Director of the Texas Agricultural Experiment Station. Received for publication June 11, 1945.

[2]Agronomist and Agronomist in Charge of Sorghum Investigations, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 935.

certain constituents of the environment since such things as photoperiod, temperature, and nitrogen nutrition level have been found to influence floral initiation. The correlative effects of temperature and nitrogen nutrition on photoperiodism are discussed by Hamner (13).

Annual and biennial growth habits such as exist in sweetclover and sugar beets and winter and spring growth habits such as exist in small grains as well as early and late maturities such as exist in summer-growing annuals are all the result of difference in time of floral initiation. These differences in maturity, even though they occur in both long- and short-day species, are apparently all of the same sort since each is dependent upon the time of floral initiation. Genes that control time of maturity have been reported in sugar beets by Abegg (2) and Owen, Carsner, and Stout (23); in sweetclover by Smith (30); in tobacco by Allard (3); in rice by Hector (16) and Bhide (6); in sorghum by Karper (18) and Ayyangar, *et al.* (5); in sweet peas by Little and Kantor (22); and in corn by Sprague (32). Winter and spring growth habits in wheat and barley have been demonstrated by numerous workers to be genetically controlled and the literature on this subject is cited in a paper by Powers (24). Statistical methods have been used to analyze data of a quantitative nature in an effort to establish the number of genes involved in varietal crosses in a number of species, including peas, cotton, tomatoes, and golden-rod. This literature is cited in a paper by Goodwin (11).

In a number of instances it is known that a difference in response to photoperiod, or to photoperiod and temperature combined, is the difference between the genes that influence time of maturity. This is true in tobacco as shown by Allard (3), in wheat as shown by Powers (24), in sugar beets as shown by Owen, *et al.* (23), in golden-rod as shown by Goodwin (11), and in *Zea* as shown by Langham (21) provided the proposal of Reeves and Mangelsdorf (25) to make *Zea* and *Euchlaena* congeneric is accepted. Of course, not all differences in maturity among varieties are caused by differences in response to photoperiod. The later maturing and simple recessive mutation Cuzcoid in corn which resembles a variety from equatorial regions, for example, has been reported by Sprague (32) as not being influenced by photoperiod.

A review of the literature leads to the conclusion that, in grasses, differences in dates of maturity among varieties are the result of differences in time of floral initiation; that time of floral initiation is influenced by genes that are themselves influenced in expression by constituents of the environment such as photoperiod, temperature, and nitrogen nutrition level; that time of floral initiation determines not only the date of maturity but, also, ultimate plant size; and that a biochemical process involving some hormone-like substance is involved in stimulating the differentiation that leads to floral initiation.

MATERIALS AND METHODS

All of the numerous sorghum varieties are considered by American workers to be of one species, *Sorghum vulgare*, Pers. A classification of American varieties, none of which is indigenous, and a careful review of the botanical literature is given by Vinall, Stephens, and Martin (36). Snowden (31) has considered that sorghum consists of many species and has made a botanical classification of sorghums throughout the world based on the collection at Kew Gardens. There may be a little justification for this specific classification, but all of the 10-chromosome varieties (or species) intercross readily, are highly fertile, and the segregation of numerous genes in the F_2 generation follows a normal Mendelian pattern. Nevertheless, there are distinct groups of varieties, the genetic basis for which is not understood, and they are generally referred to in the United States as the broomcorns, sumacs, milos, kafirs, kaoliangs, shallus, etc. In the study reported here only varieties of the milo group, which is Snowden's *Subglabrescens* var. *latum*, are involved.

The milos comprise a group of grain sorghum that is visibly distinct largely as the result of the recurved peduncles, yellow midribs, ovoid panicles, wrinkled glumes, and characteristically shaped seeds (Fig. 1). Like other sorghum varieties, the various strains of milo are actually inbred lines whose vigor is not reduced by further inbreeding. In the milo group the differences between varieties are brought about by differences in two genes that influence length of internode, by one gene that determines the presence or absence of a plant pigment, and by

FIG. 1.—Early and Intermediate genotypes of milo that differ only in one gene that influences time of floral initiation. Sooner milo on left and Dwarf Yellow milo on right.

the genes that influence internode number and maturity, the inheritance of which is the subject of this paper.

The inheritance of the two genes that influence internode length in milo was studied by Karper (17) and is the same as that in broomcorn as reported by Sieglinger (27). Both genes in the dominant (*Dw* Dw_2) condition produce a tall plant; one recessive and one dominant produce two kinds of dwarf plants which are, for convenience, called dwarf (*dw* Dw_2) and tall dwarf (*Dw* dw_2); and both genes in the recessive condition produce a double dwarf plant (*dw* dw_2). All of the height classes within a single maturity type have the same number of leaves, the difference between them being in the internode length only.

Red or yellow pericarp color in milo was shown by Conner and Karper (8) to be due to a single dominant gene. The dominant gene produces a red plant color that shows in the dead tissue and a red (in varietal names called yellow) pericarp. The recessive allelomorph produces plants lacking the red pigment in both foliage and pericarp. This gene in the dominant condition is common to all red-seeded American varieties and was designated as *R* by Vinall and Cron (35), Sieglinger (26), and Swanson (34). It appears that this same gene was called *R* by Graham (12) in India but Ayyangar, *et al.* (4) called it *W* and assigned *R* to another gene. In this paper the designation *R* will be used for the gene that produces the difference in color between red and white which is the difference between Yellow milo and White milo.

In addition to the differences in height and seed color, there are varieties of two different maturities being grown in the United States and a third maturity type was grown 40 years ago but is now extinct. The commercial varieties of milo being grown in the United States may be either tall, dwarf, or double dwarf in height; either yellow or white seeded; and either early or mid-season in maturity. All of these possible combinations are not being grown commercially, but most of

them do exist and are in sorghum nurseries on experiment stations. The early maturing varieties are Early White milo (tall) and Sooner milo (dwarf and yellow). The varieties of intermediate maturity are Double Dwarf Yellow milo, Dwarf Yellow milo, Dwarf White milo, Standard Yellow milo (tall), and Standard White milo (tall).

Beginning in 1938, a study of the inheritance of the genes that bring about differences in maturity in sorghum was undertaken and this study is still under way. The work is being done at the Chillicothe and Lubbock Stations. The difference in latitude at the two stations is not great, Lubbock being slightly south and Chillicothe slightly north of the 34th degree of North Latitude; and, therefore the length of day is practically the same at the two locations. The longest day in the year from sunrise to sunset at the 34th parallel is approximately 14 hours and 25 minutes. The elevation at Lubbock is 3,240 feet and at Chillicothe is 1,406 feet and this difference in elevation brings about a considerable difference in temperature that is reflected in a shorter growing season at Lubbock and enough difference in temperature to affect growth of sorghum. During June and July there is a difference of about 6 degrees in the daily minimum (night) temperature and 3 degrees in the daily maximum (day) temperature, those at Chillicothe being higher in each case. Detailed meterological data of the two stations have been published (19).

Plantings at Lubbock were made during the last week of May and those at Chillicothe usually during the third week of June. The later planting at Chillicothe was done in an effort to escape chinch bug infestation as that insect migrates from wheat by flight early in June.

Measurements of height were made from the ground level to the ligule of the upper (flag) leaf. This height measurement is entirely comparable in the various heights and is much easier to measure than total height in populations of milo where many of the heads are recurved. Number of leaves per plant was obtained by marking the fifth and subsequently the tenth leaf soon after each appeared. The tenth leaf is still on the plant at maturity and the total number of leaves was obtained by counting upward from it. Length of leaf determinations were made by measuring the length of the leaf blade from the ligule to the tip of the leaf. Diameter of stalk was measured at the middle of the first internode that appeared above the ground level. The internode measured was usually the twelfth. The constants included in Tables 6 and 7 are based upon populations of 30 to 40 plants. Weights given in Table 7 are of air-dry material.

A tag showing the number of days from planting until anthesis was placed on the head of each main stalk on the day its first bloom appeared. The information on these tags was later tabulated by 2-day periods. Details concerning the flowering of sorghum may be found in a paper by Stephens and Quinby (33).

The time of floral initiation or head differentiation may be determined readily by splitting plants and observing the growing points under low magnification.

In the experiments when plants were subjected to 10-hour photoperiods, frames covered first with black rubberized cloth and then with white sheeting were placed over the plants being treated at 5:00 p.m. and removed at 7:00 a.m.

EXPERIMENTAL RESULTS

Four phenotypes for maturity have been obtained as segregation products resulting from crossing certain strains of milo. The four phenotypes include eight genotypes which result from the various combinations of three independently inherited genes. Typical distributions of time of anthesis of the eight genotypes is given in Table 1. For the sake of convenience, the four phenotypes have been given the designations of Early, Intermediate, Late, and Ultra-late. The three genes have been assigned the symbols Ma, Ma_2, and Ma_3. The genes Ma_2 and Ma_3 are dependent for their expression on the presence of dominant Ma and this condition causes all four genotypes that are homozygous recessive for ma to be of the same Early phenotype.

Also, in the presence of dominant Ma_2, dominant Ma_3 does not express itself and there are two Ultra-late genotypes that have similar phenotype.

The Early genotypes comprise the agronomic strains of the Sooner milo variety. The Intermediate genotype comprises all of the agronomic varieties of Yellow and White milo whether double-dwarf, dwarf, or tall in height. The Late genotype is not represented by an agronomic variety. The Ultra-late genotype became extinct as a variety in the United States when Giant milo disappeared about 1900.

Ayyangar, *et al.* (5) in India studied the inheritance of a gene that caused "tall-late" plants in sorghum. The mutation was discovered in a common variety, Patcha jonna, and was found to be caused by a single recessive gene. The symbols In_1 and in_1 were assigned to the factor pair. It is not known if any of the three genes in milo reported here is identical with In_1, but the linage of In_1 with height of plant suggests that In_1 and Ma_1 may be identical. However, it will be noticed that there is a reversal of dominance for late maturity in In_1 as compared with Ma, Ma_2, and Ma_3. Earliness is dominant to lateness in most crosses between American varieties if neither Dwarf Yellow milo nor Hegari is one of the parents. This fact is shown by the time of maturity of first generation hybrids as reported by Karper and Quinby (20) and by unpublished data.

INHERITANCE OF *Ma*

The mode of inheritance of the *Ma* gene is shown by the F_2 and F_3 data of S. A. 5458, Dwarf Yellow milo (Intermediate)×Sooner milo (Early). The F_1 plant and the F_2 and F_3 populations were grown at Chillicothe in 1942, 1943, and 1944. Genetically, the cross was $Ma\ ma_2\ ma_3 \times ma\ ma_2\ ma_3$, and the F_1 hybrid which bloomed in 85 days from planting was $Ma\ ma\ ma_2\ ma_2\ ma_3\ ma_3$. The F_2 population was tagged for time of anthesis and the entire population of 192 heads was grown into the F_3 and tagged for time of anthesis and, therefore, the F_2 genotypic segregation is available. The data are given in Table 2. The parental classes have means for anthesis of 50.5 and 71.5 days and their periods of anthesis are distinct. The heterozygous class is later and distinct from the Intermediate parental class except that the 6 latest individuals of the parental class and the 16 earliest individuals of the heterozygous class bloomed during the same 4-day period. The F_3 data show the F_2 segregation to be for only one gene as the distribution for blooming gave a close fit to a 1:2:1 ratio for Intermediate, Intermediate-heterozygous, and Early genotypes. The X^2 is .292 and the P is .90.

The late blooming of the heterozygous class, which is the result of the heterozygotes having about two more leaves than the Intermediate parent, can be explained in a number of ways, only two of which will be mentioned. The interaction of genes *Ma* and *ma* could be different from that of the two dominant allelomorphs and, if this should be the case, it would have a bearing on theories of heterosis. However, there is a possibility that there may be a gene closely linked to the *Ma* gene. If such is the case, the Early (*ma ma*) parent

TABLE 1.—*Frequency distribution of flowering of eight milo maturity genotypes; data from a June 20, 1944, planting at Chillicothe, Texas.*

Days from planting to anthesis	Phenotype							
	Early				Inter-mediate	Late	Ultra-late	
	Genotype *ma* ma_2ma_3	Genotype *ma* ma_2Ma_3	Genotype *ma* Ma_2ma_3	Genotype *ma* Ma_2Ma_3	Genotype *Ma* ma_2ma_3	Genotype *Ma* ma_2Ma_3	Genotype *Ma* Ma_2ma_3	Genotype *Ma* Ma_2Ma_3
42	—	—	—	—	—	—	—	—
44	—	1	—	—	—	—	—	—
46	—	6	18	—	—	—	—	—
48	4	23	21	4	—	—	—	—
50	11	4	4	22	—	—	—	—
52	12	1	1	11	—	—	—	—
54	4	3	—	4	—	—	—	—
56	—	1	—	3	—	—	—	—
58	—	—	—	—	—	—	—	—
60	—	—	—	—	—	—	—	—
62	—	—	—	—	—	—	—	—
64	—	—	—	—	15	—	—	—
66	—	—	—	—	11	—	—	—
68	—	—	—	—	2	—	—	—
70	—	—	—	—	3	—	—	—
72	—	—	—	—	4	—	—	—
74	—	—	—	—	—	—	—	—
76	—	—	—	—	—	4	—	—
78	—	—	—	—	—	12	—	—
80	—	—	—	—	—	5	—	—
82	—	—	—	—	—	13	—	—
84	—	—	—	—	—	10	—	—
86	—	—	—	—	—	7	—	—
88	—	—	—	—	—	1	—	—
90	—	—	—	—	—	4	—	—
92	—	—	—	—	—	—	1	—
94	—	—	—	—	—	—	25	1
96	—	—	—	—	—	—	18	6
98	—	—	—	—	—	—	12	1
100	—	—	—	—	—	—	1	3
Mean	51.0 ± .1	48.6 ± .4	47.5 ± .2	51.1 ± .2	66.2 ± .4	82.1 ± .5	95.5 ± .2	97.1 ± .6

TABLE 2.—*Frequency distribution of flowering of F_2 population segregating for Ma and ma based on classification of F_3 rows; S.A. 5458, Dwarf Yellow milo (Intermediate)×Sooner milo (Early). F_2 grown at Chillicothe, Texas, from a planting on June 19, 1943.*

Days from planting to anthesis	F_2 genotypic distribution			Total F_2 frequency
	Intermediate *Ma Ma*	Intermediate-heterozygous *Ma ma*	Early *ma ma*	
44	—	—	—	—
46	—	—	1	1
48	—	—	7	7
50	—	—	23	23
52	—	—	12	12
54	—	—	2	2
56	—	—	—	—
58	—	—	1	1
60	—	—	—	—
62	—	—	—	—
64	4	—	—	4
66	1	—	—	1
68	4	—	—	4
70	12	—	—	12
72	7	—	—	7
74	13	—	—	13
76	3	6	—	9
78	3	10	—	13
80	—	8	—	8
82	—	15	—	15
84	—	26	—	26
86*	—	4	—	4
88	—	22	—	22
90	—	5	—	5
92	—	3	—	3
94	—	—	—	—
Observed	47	99	46	192
Calculated 1:2:1	48	96	48	192
X^2	.021	.094	.083	.198

P=.90

*Date of bloom of F_1 plant.

would carry the dominant allel but this could not express itself in the absence of dominant *Ma*. In the heterogygote (*Ma ma*) the new gene linked with recessive *ma* would express itself, making the heterozygous plant later than the Intermediate parent. Assuming this to be the true state of affairs, a cross-over in F_1 would result in an F_2 plant that would produce gametes with both dominants. Such a plant would produce an F_3 row segregating for Intermediate maturity and a maturity about 10 days later. No such row has been observed among about 450 rows from three different populations. The evidence appears to point to an interaction between *Ma* and *ma* that delays floral initiation as being the most likely explanation.

INHERITANCE OF *Ma* AND *Ma_2*

The mode of inheritance of Ma_2 is shown by the F_2 and F_3 data of S. A. 5283, Sooner milo (Early)×Dwarf Yellow milo (Inter-

mediate). The F_1 plant and those populations were grown at Lubbock in 1941, 1942, and 1943. Genetically the cross is *ma* Ma_2 ma_3 × *Ma* ma_2 ma_3 and the F_1 hybrid is *Ma ma* Ma_2 ma_2 ma_3 ma_3. The F_2 distribution for anthesis is given in Table 3 and shows that due to recombination there is a class later than the Intermediate parent. The F_2 phenotypic distribution is a close fit to a 9:3:4 ratio. The 159 F_2 heads were grown into the F_3 and each plant was tagged for day of anthesis. The F_2 genotypic segregation is available, therefore, and is also presented in Table 3. As shown by a X^2 of 1.450 and a P of .90 there is a close fit to the 1:2:2:4:1:2:4 ratio expected from a segregation for two genes with epistasis of recessive *ma* over dominant Ma_2. It is apparent that the presence of dominant *Ma* is necessary before Ma_2 can express itself. The late-maturing class that appeared due to a new combination of *Ma* and Ma_2 is one of the Ultra-late genotypes and is genetically *Ma* Ma_2 ma_3. A delay in maturity as a result of the heterozygous condition of the *Ma* gene is not very apparent in the data in Table 3 but was quite evident in the F_3 data.

INHERITANCE OF *Ma*, Ma_2, AND Ma_3

The discovery of a third gene affecting maturity in milo was not anticipated and since its discovery there has not been time to again cross the appropriate varieties and to grow the three generations necessary to have comparable data on inheritance to present. The presence of the third gene might well have gone undetected or the difference caused by it attributed to modifying genes had not a genotype that bloomed in the interval between Intermediate and Ultra-late genotypes always had a white pericarp. Following the recognition of this Late genotype and the indicated linkage between the third gene and the gene *R* that causes presence or absence of a plant pigment, an additional linkage was discovered between *Ma* and dw_2, one of the genes that influences the lengthening of the internode. This second linkage contributed to the determination of the mode of inheritance when all three genes are involved because the heterozygous nature of the plants of the constitution *Ma ma* could be detected by the height of the plants. Since the heterozygous condition of the first gene (*Ma ma*) brings about a delay in blooming which places a heterozgyous individual in a maturity class roughly similar to the next latest maturing homozygous class, the mode of inheritance would hardly have been recognized in the absence of the linkage between *Ma* and dw_2.

Several F_2 populations of about 50 each segregating for all three genes have been grown into the F_3 but only one population of 57 plants also involved the linkage of maturity with height. It happens that this population contained 22 Early plants but only 9 plants without pigment, whereas the figures in both cases should have been 14 since both should have been 25% of the population. These departures are statistically beyond expectation due to chance and make the F_2 population itself of questionable value, particularly so when the other populations were normal with respect to numbers in both the Early maturity and recessive white classes.

S.A. 5283, Sooner milo (Early) × Dwarf Yellow milo (Intermediate), F_2 grown at Lubbock, Texas, from a planting on May 29, 1942.

Days from planting to anthesis	F_2 genotypic distribution							Total F_2 frequency
	Ultra-late				Intermediate		Early	
	Genotype $Ma\ Ma\ Ma_2Ma_2$	Genotype $Ma\ Ma\ Ma_2ma_2$	Genotype $Ma\ ma\ Ma_2Ma_2$	Genotype $Ma\ ma\ Ma_2ma_2$	Genotype $Ma\ Ma\ ma_2ma_2$	Genotype $Ma\ ma\ ma_2ma_2$	Genotypes $ma\ ma\ Ma_2Ma_2$ $ma\ ma\ Ma_2ma_2$ $ma\ ma\ ma_2ma_2$	
60	—	—	—	—	—	—	14	14
62	—	—	—	—	—	—	8	8
64	—	—	—	—	—	—	6	6
66	—	—	—	—	—	—	6	6
68	—	—	—	—	—	—	3	3
70	—	—	—	—	—	—	—	—
72	—	—	—	—	2	1	2	5
74	—	—	—	—	—	—	—	—
76	—	—	—	—	—	2	—	2
78	—	—	—	—	1	7	—	8
80	—	—	—	—	—	2	—	2
82	—	—	—	—	3	3	—	6
84	—	—	—	—	—	4	—	4
86	—	—	1	—	—	—	—	1
88	—	—	—	—	1	4	—	5
90	1	—	—	—	—	—	—	1
92	—	1	—	1	—	—	—	2
94	—	—	—	—	—	—	—	—
96	1	—	—	—	—	—	—	1
98	—	—	—	—	1	—	—	1
100	—	—	—	7	—	—	—	7
102	—	3	1	4	—	—	—	8
104	1	3	1	3	—	—	—	8
106	3	2	9	7	1	—	—	22
108	—	3	1	7	—	—	—	11
110	1	—	2	10	—	—	—	13
112	—	3	3	3	—	—	—	9
114	1	3	1	1	—	—	—	6
Observed	8	18	19	43	9	23	39	159
Calculated	10	20	20	40	10	20	40	160
X^2	.400	.200	.050	.225	.100	.450	.025	1.450

P = .90

The F_3 rows which were grown in 1944 at Chillicothe contained about 50 plants as a usual thing which is sufficient to allow each homozygous type to appear in case three genes were segregating. However, on account of the two linkages, it was possible to identify the genotype of 25 rows exclusive of the 22 Early rows and 10 in which there were no plants. The segregation within these 25 rows showed that they were of 13 different genotypes. Since the total number of genotypes, exclusive of Early ones, that could result from the segregation of two genes is six, it is apparent that three genes were segregating. Assuming three genes, the number of different genotypes exclusive of Early ones would be 18, and 13 of these were represented among the 25 rows as mentioned previously.

The data from these F_3 rows indicate that the F_1 plant, Early White milo × Double Dwarf Yellow milo (ignoring the gene *dw* which is inherited independently), is genetically $\frac{Ma}{dw_2}\ \frac{ma}{Dw_2}\ Ma_2 ma_2\ \frac{Ma_3}{r}\ \frac{ma_3}{R}$. The data also indicate that this third gene, Ma_3, like Ma_2, does not express itself except in the presence of dominant *Ma*, and also that Ma_3 does not delay maturity if Ma_2 is also present in the dominant condition. These circumstances apparently bring about frequencies of genotypes and phenotypes as shown in Table 4. It will be noticed that all of the genotypes heterozygous for the first gene are shown as having a phenotype different from their corresponding homozygous genotypes. The Intermediate-heterozygous and Late-heterozygous have always been observed to be later than Intermediate and Late genotypes, respectively. However, Ultra-late-heterozygous genotypes have not always appeared to be different from their corresponding homozygous genotypes and so the class limits for time of bloom for all Ultra-late classes, whether homozygous or heterozygous, are shown as being the same. When more data are available it seems likely that the Ultra-late homozygous and heterozygous genotypes will be found to be different. When the classes for time of blooming are assembled there is a 42:5:1:16 phenotypic ratio for Ultra-late plus Late-heterozygous, Late plus Intermediate-heterozygous, Intermediate, and Early genotypes. The 13 genotypes that contained dominant *Ma* that appeared among the 25 rows are marked with an asterisk in Table 4. It is presumed that most or all of the genotypes recessive for *ma* appeared also.

LINKAGE RELATIONSHIPS

Not enough data are available to arrive at a reliable cross-over-percentage between the genes *Ma* and dw_2 or between Ma_3 and *r*. However, among the 47 plants of the population S. A. 5155 whose genotype for *Ma and* Dw_2 could be identified by their F_3 rows, there were eight cross-overs. These figures would indicate that crossing-over between *Ma* and dw_2 is in the neighborhood of 8%.

Cross-overs between the third gene and *R* among the 25 plants of the same population of 47, each of which had at least one gene dominant for *Ma*, amount to two. These figures would indicate a crossing-over between Ma_3 and *r* in the neighborhood of 4%.

cross-over classes.

Expected frequency	F_2 genotype	F_2 phenotype			
		Maturity	Pericarp color	Height	Class limits of days from planting to anthesis
1	$Ma\ Ma\ Ma_2\ Ma_2\ Ma_3\ Ma_3$	Ultra-late	white	dwarf	92–106
2	$Ma\ Ma\ Ma_2\ Ma_2\ Ma_3\ ma_3$	Ultra-late	red	dwarf	92–106
2	$Ma\ Ma\ Ma_2\ ma_2\ Ma_3\ Ma_3$	Ultra-late	white	dwarf	92–106
2	$Ma\ ma\ Ma_2\ Ma_2\ Ma_3\ Ma_3$*	Ultra-late-heterozygous	white	tall	92–106
4	$Ma\ Ma\ Ma_2\ ma_2\ Ma_3\ ma_3$*	Ultra-late	red	dwarf	92–106
4	$Ma\ ma\ Ma_2\ Ma_2\ Ma_3\ ma_3$*	Ultra-late-heterozygous	red	tall	92–106
4	$Ma\ ma\ Ma_2\ ma_2\ Ma_3\ Ma_3$*	Ultra-late-heterozygous	white	tall	92–106
8	$Ma\ ma\ Ma_2\ ma_2\ Ma_3\ ma_3$*	Ultra-late-heterozygous	red	tall	92–106
1	$Ma\ Ma\ Ma_2\ Ma_2\ ma_3\ ma_3$*	Ultra-late	red	dwarf	92–106
2	$Ma\ Ma\ Ma_2\ ma_2\ ma_3\ ma_3$*	Ultra-late	red	dwarf	92–106
2	$Ma\ ma\ Ma_2\ Ma_2\ ma_3\ ma_3$*	Ultra-late-heterozygous	red	tall	92–106
4	$Ma\ ma\ Ma_2\ ma_2\ ma_3\ ma_3$*	Ultra-late-heterozygous	red	tall	92–106
1	$Ma\ Ma\ ma_2\ ma_2\ Ma_3\ Ma_1$*	Late	white	dwarf	76–88
2	$Ma\ Ma\ ma_2\ ma_2\ Ma_3\ ma_3$	Late	red	dwarf	76–88
2	$Ma\ ma\ ma_2\ ma_2\ Ma_3\ Ma_3$	Late-heterozygous	white	tall	90–98
4	$Ma\ ma\ ma_2\ ma_2\ Ma_3\ ma_3$*	Late-heterozygous	red	tall	90–98
1	$ma\ ma\ Ma_2\ Ma_2\ Ma_3\ Ma_3$	Early	white	tall	46–60
2	$ma\ ma\ Ma_2\ Ma_2\ Ma_3\ ma_3$	Early	red	tall	46–60
2	$ma\ ma\ Ma_2\ ma_2\ Ma_3\ Ma_3$	Early	white	tall	46–60
4	$ma\ ma\ Ma_2\ ma_2\ Ma_3\ ma_3$	Early	red	tall	46–60
1	$Ma\ Ma\ ma_2\ ma_2\ ma_3\ ma_3$	Intermediate	red	dwarf	64–74
2	$Ma\ ma\ ma_2\ ma_2\ ma_3\ ma_3$*	Intermediate-heterozygous	red	tall	76–88
1	$ma\ ma\ Ma_2\ Ma_2\ ma_3\ ma_3$	Early	red	tall	46–60
2	$ma\ ma\ Ma_2\ ma_2\ ma_3\ ma_3$	Early	red	tall	46–60
1	$ma\ ma\ ma_2\ ma_2\ Ma_3\ Ma_3$	Early	white	tall	46–60
2	$ma\ ma\ ma_2\ ma_2\ Ma_3\ ma_3$	Early	red	tall	46–60
1	$ma\ ma\ ma_2\ ma_2\ ma_3\ ma_3$	Early	red	tall	46–60

*F_2 individuals of these 13 classes appeared among the 25 plants of S.A. 5155 that were dominant for *Ma* and produced viable seed. It is presumed that the various genotypes recessive for *ma* appeared among the 22 Early plants, but there is no way to distinguish between the nine genotypes.

THREE TYPES OF INTERNODAL DISPOSITION

Ayyangar, *et al.* (5) made a general classification of sorghum varieties into early, medium, and late and concluded that varieties in the early classification have culms whose internodes become progressively longer from the ground to the peduncle. Plants of this kind were called "ever increasing". Varieties in the medium group were called "unimodal" as they have one short internode between others that are longer below and above. Late varieties were called "bimodal" since they have a double rise and fall in internode length ending with a final rise toward the peduncle.

The milo strains fit this classification as the Early strains have internodes that from the ground up increase in length; the Intermediate strain has one shortening of internodes close to the top followed by a few longer internodes; and the Late and Ultra-late strains have two areas of construction, one close to the ground and the other close to the top. Under 10-hour photoperiods all strains have internode lengths that increase progressively from the ground to the peduncle.

NATURE OF GENES *Ma*, Ma_2, AND Ma_3

Summer-grown crops of the various milo phenotypes are distinctly different in time of anthesis but these same phenotypes and F_1 plants resulting from crosses between them are all extremely early and quite similar in maturity if grown in the greenhouse during the winter season of short photoperiods.

An F_2 population of a cross between Sooner milo (Early, $ma\ ma_2ma_3$) $\times$ Dwarf White milo (Intermediate, $Ma\ ma_2ma_3$) and the two parents were grown under both 10-hour and normal photoperiods at Chillicothe in the summer of 1941. The plants were tagged for time of anthesis and the data are recorded in Table 5. Under the 10-hour photoperiod, the two parents bloomed on the 46th day; and the blooming of the F_2 generation was distributed from 42 to 56 days with a mode on 44 days. Under natural conditions, with the photoperiod about 14 hours, the Early parent bloomed on the 56th day and the Intermediate parent on the 78th day. The blooming of the F_2 generation under normal day fell into two classes with the Early 25% of the population distributed between 50 and 62 days with a mode on 58 days; and 75% of the population, representing the Intermediate and Intermediate-heterozygous classes, distributed between 66 and 88 days. A picture of these populations is shown in Fig. 2. It is apparent that a long photoperiod is necessary before the dominant condition of the *Ma* gene can express itself, or it could be said that the gene *Ma* influences the response of the plant to photoperiod.

In 1944, four milo genotypes, Early ($ma\ ma_2ma_3$), Intermediate ($Ma\ ma_2ma_3$), Late ($Ma\ ma_2Ma_3$), and Ultra-late ($Ma\ Ma_2ma_3$), were planted at Chillicothe on June 20 and subjected to both normal and 10-hour photoperiods. Under normal photoperiod, the different genotypes initiated their heads at different times and had distinctly different distributions of anthesis, but under 10-hour photoperiods each genotype had initiated its heads on the 19th day. As a conse-

FIG. 2.—Untreated and treated F_2 populations of Early × Intermediate milo. Two bundles on left are one population and show segregation for maturity when grown under natural photoperiods. Bundle on right is population planted from same seed but which was subjected to 10-hour photoperiods.

TABLE 5.—*Distribution of flowering of F_2 population heterozygous for Ma and ma under both 10-hour and 14-hour photoperiods; S.A. 1486, Sooner milo (Early, ma)×Dwarf White milo (Intermediate, Ma) from a planting at Chillicothe, Texas, made on July 3, 1941.*

Number of days from planting to anthesis	Distribution of flowering of F_2 population under	
	10-hour photoperiod	14-hour photoperiod
42	4	—
44	21	—
46*	13	—
48	8	—
50	8	1
52	1	1
54	7	1
56†	5	5
58	—	6
60	—	1
62	—	2
64	—	—
66	—	3
68	—	3
70	—	1
72	—	2
74	—	1
76	—	7
78‡	—	13
80	—	9
82	—	5
84	—	4
86	—	3
88	—	1
90	—	—
Total....................	67	69

*Flowering time of both parents under 10-hour photoperiod.
†Flowering time of Early parent under 14-hour photoperiod.
‡Flowering time of Intermediate parent under 14-hour photoperiod.

quence, the leaf numbers and blooming distributions of all genotypes under the 10-hour day were similar if not identical. A summary of the data is presented in Table 6.

It has already been shown that the gene *Ma* influences the response of the plant to photoperiod, but these additional data are not illuminating in regard to the nature of genes Ma_2 and Ma_3. They do show, however, that Ma_2 and Ma_3 are not able to express themselves in the presence of the condition that produces early floral initiation whether that condition is brought about by the recessive condition of the *Ma* gene or by the administration of short photoperiods that causes the dominant *Ma* to react like recessive *ma*. It is presumed that the various genotypes resulting from the various combinations of the three genes, excluding the four genotypes that are recessive for *ma*, have different critical photoperiods. If this should be true, it would indicate that Ma_2 and Ma_3 also influence response to photoperiod.

The soybean, a short-day plant, has been shown by Borthwick

and Parker (7) to have varieties with different critical photoperiods and "in general, the earlier the variety matures the longer the photoperiod on which floral initiation can occur". A similar situation undoubtedly exists in milo and the Early genotype could be said to have the highest critical photoperiod and the Ultra-late genotype the lowest.

It is well known that temperature affects the photoperiodic expression of plants. Day and night temperatures are, respectively, 3 and 6 degrees lower at Lubbock than at Chillicothe during June and it is thought that these lower temperatures are responsible for the difference in time of flowering of the several genotypes at the two locations. This difference in time of anthesis of several of the genotypes may be seen by consulting Tables 1 and 3. The Early genotype at Lubbock usually blooms between 60 and 70 days, but at Chillicothe the blooming is between 44 and 56 days. The Intermediate genotype at Lubbock blooms between 72 and 82 days but between 64 and 72 days at Chillicothe. The Ultra-late genotype at Lubbock blooms between 90 and 114 days but between 90 and 100 days at Chillicothe. In all cases there is a delay in blooming at Lubbock as compared with that at Chillicothe, and the smaller difference in time of blooming between Early and Intermediate genotypes at Lubbock makes the two genotypes more nearly similar in appearance at Lubbock than at Chillicothe.

TABLE 6.—*The effect of 10- and 14-hour photoperiods upon the time of floral initiation and anthesis and number of leaves of four milo maturity genotypes, data from a June 20, 1944, planting at Chillicothe, Texas.*

	Genotype			
	Early $ma\ Ma_2ma_3$	Intermediate $Ma\ ma_2ma_3$	Late $Ma\ ma_2Ma_3$	Ultra-late $Ma\ Ma_2ma_3$
	Number of Days to Floral Initiation			
10-hour photoperiod...	19	19	19	19
14-hour photoperiod...	32	37	41	70
	Number of Days to Anthesis			
10-hour photoperiod...	43.6±.4	44.2±.3	46.4±.6	46.7±.9
14-hour photoperiod...	48.6±.3	68.6±.4	82.6±.7	102.4±.4
	Number of Leaves			
10-hour photoperiod...	12.2±.1	12.3±.1	12.2±.2	12.6±.2
14-hour photoperiod...	16.4±.1	22.0±.1	23.5±.3	31.5±.2

According to the hormone theory, the initiation of floral parts awaits the accumulation of a floral hormone in sufficient concentration to allow a floral bud rather than a leaf to be differentiated. Assuming the soundness of this theory, these three genes in milo that bring about differences in maturity actually hasten either the

synthesis or the destruction of the floral hormone. Whether synthesis or destruction of the hormone is the action of these genes, the action is a typical one involving a change in rate. Since the process that is influenced by the action of the genes is a biochemical one, it is easy to comprehend how temperature could influence the rate of reaction.

SIZE ASSOCIATED WITH TIME OF FLORAL INITIATION

Under 10-hour photoperiods, which induce simultaneous floral initiation in all milo maturity genotypes, the several genotypes are obviously similar in size and are quite small. Under 14-hour photoperiods the various genotypes are quite dissimilar in size, the earliest in maturity being the smallest as shown in Figs. 1 and 3.

The data in Table 7 show that the duration of the vegetative period is positively correlated with plant size, the best measure of which is total dry weight of plant. The figures show that a two-fold difference in size resulted due to the action of two genes since the Early strain (*ma* Ma_2ma_3) weighed 0.43 pound per plant while the Ultra-late strain (*Ma* Ma_2ma_3) weighed 0.97 pound per plant. This difference in size is apparently the result of the time element alone and not to a difference in rate of growth, because there is no appreciable difference in the time that corresponding successive leaves appear on the four genotypes. The fact that larger leaves appear on the later maturing genotypes indicates only that the growing point continues to grow in circumference from day to day and a leaf arising from a higher node would be expected to be larger than one arising from a lower node. The measurements given in Table 7 were made on the 13th, 19th, 20th, and 23rd leaves, respectively, for the Early, Intermediate, Late, and Ultra-late strains. These leaves which were, on the average, the largest on the plants were the third from the top on the first three strains and the eighth from the top on the Ultra-late strain. Apparently high temperatures and an accompanying drought that occurred during August and between the 40th and 58th days following planting had an adverse affect on the circumference of the

TABLE 7.—*Figures showing the size of four milo maturity genotypes grown under normal photoperiods, data from a June 20, 1944, planting at Chillicothe, Texas.*

	Genotype			
	Early *ma* Ma_2ma_3	Intermediate *Ma* ma_2ma_3	Late *Ma* ma_2Ma_3	Ultra-late *Ma* Ma_2ma_3
Number of days to anthesis	48.6 ±0.3	68.6 ±0.4	82.6 ±0.7	102.4 ±0.4
Number of leaves	16.4 ±0.1	22.0 ±0.1	23.5 ±0.3	31.5 ±0.2
Height of plant, cm	85.8 ±1.2	87.7 ±1.3	121.6 ±3.4	151.8 ±2.7
Length of leaf, cm	54.1 ±1.5	65.1 ±0.5	65.3 ±0.8	78.1 ±0.5
Diameter of stalk, cm	1.42±0.02	2.30±0.04	2.22±0.05	2.53±0.01
Weight of head, lbs	0.24±0.02	0.36±0.02	0.33±0.03	0.27±0.02
Weight of plant, lbs	0.43±0.03	0.62±0.04	0.64±0.04	0.97±0.06

growing point of the undifferentiated Ultra-late strain even though nodes continued to be laid down at about a constant rate.

The weight of heads is a figure of particular interest because of the practical importance of grain production. It seems reasonable to suppose that there would be a high positive correlation between total plant growth and weight of grain. This correlation undoubtedly exists unless a large-growing (late-maturing) strain makes more growth than the available soil moisture will support as apparently happened with the Ultra-late strain at Chillicothe in 1944. The fact that the upper seven leaves of the Ultra-late strain were smaller than the eighth from the top shows that a larger head would have been formed had the floral initiation taken place seven leaves earlier.

Under the growing conditions that existed in 1944 and which were quite typical of the usual conditions, the strains ranked in the order of Intermediate, Late, Ultra-late, and Early from the standpoint of grain production. During the unusually favorable season of 1942, grain productions of Early, Intermediate, and Ultra-late strains

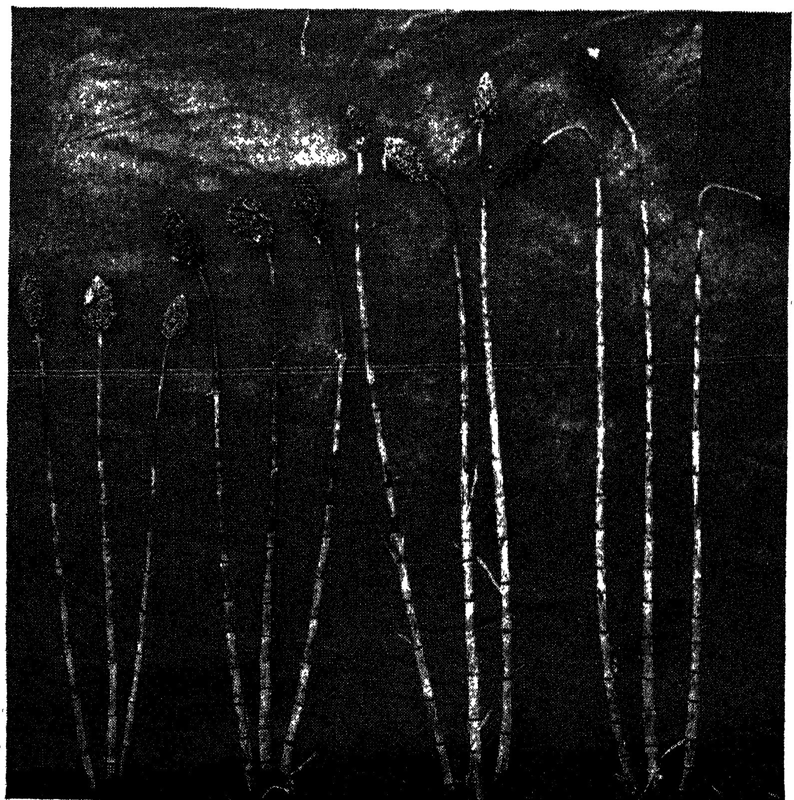

FIG. 3.—From left to right, Early, Intermediate, Late, and Ultra-late genotypes of milo that differ in the genes that affect time of floral initiation.

were 27, 36, and 54 bushels per acre, respectively. The differences in size, as shown by the data in Table 7, indicate what a profound change can result from the action of a few genes that influence duration of vegetative growth.

Some additional data are presented in Table 7 so that the morphological relationships of the various genotypes can be more easily understood. As would be expected, there is a positive correlation between leaf number and number of days to anthesis, height, stalk diameter, and leaf size. The fact that identical leaves appear on the different genotypes at identical times has already been mentioned and the corresponding leaves are apparently the same size. This indicates that the rate of growth of the different genotypes is identical and that the differences in size between the four genotypes is a reflection of duration of growth. The four genotypes are similar to one another in appearance except that each genotype is a larger counterpart of the one immediately preceding it in earliness of maturity.

DISCUSSION

The three genes in milo that affect duration of growth also control adaptation. The constitution of a strain with respect to adaptation genes of this sort determines not only the latitude at which it will mature but also at what altitude and in what rainfall belt it can be grown successfully as a grain crop. The correlation of small size with early maturity brings about an association of early maturity with consistent but low grain production. The highest yielding grain variety is not always the latest variety that can mature grain because moisture will usually become a limiting factor, but it is the latest variety that will mature without growth being restricted by a lack of moisture. Sooner milo, genetically an Early strain, is most consistent in grain production because it seldom exhausts the moisture supply; but it has a smaller average grain production in Texas than Dwarf Yellow milo, an Intermediate strain, which, on account of its greater growth, will produce greater yields except under conditions of extreme drought.

The correlative influence of temperature and photoperiod brings about adaptation of strains with respect to latitude and altitude. In the southern part of Texas grain sorghum is grown in a climate bordering on sub-tropical. Planting can be done when photoperiods are less than 12 hours, but the temperatures are relatively low in terms of summer temperatures. This particular combination of short photoperiod and low temperature results in greater growth of varieties that are relatively insensitive to photoperiod but less growth of photoperiod-sensitive varieties than occurs when the same varieties are grown slightly farther north during the summer months. This climatic condition in south Texas also results in relatively short periods that are favorable to planting of photoperiod-sensitive varieties.

Differences in altitude which produce differences in temperature affect the time of floral initiation. A temperature below the optimum for quick floral initiation results in larger and more productive plants.

On this account varieties not very sensitive to photoperiod that mature quickly and make little growth at Chillicothe, Texas, are quite large and productive in eastern Colorado where the elevation is close to 5,000 feet and night temperatures are relatively low. In this case it is undoubtedly temperature that causes the later maturity and greater growth.

Since sorghum is a short-day species, an increase in latitude alone delays floral initiation and increases amount of growth. On this account, strains relatively insensitive to photoperiod must be grown at high latitude even when temperatures are favorable for floral initiation, but these varieties under long photoperiods make growth comparable in size to that of the more photoperiod-sensitive varieties that are grown farther south. The general rule seems to be that any climatic condition that tends to delay floral initiation will encourage the use of varieties less sensitive to photoperiod.

The claim has sometimes been made that mutations involve only superficial characters, leaving the "fundamental" ones unaffected. The genes reported here are undoubtedly mutations of fundamental nature since they are systemic in action and have a profound effect upon duration of growth. There is always danger in assuming that the existence of a certain behavior in one plant species means that similar behavior exists in other species. However, since many of our crop plants have been or are being subjected to selection by man in environments different with respect to photoperiod and temperature from their center of origin, there is reason to believe that mutations of adaptation genes such as these in sorghums are what have been used to create varieties that differ from the original in time of maturity and in size. Similar mutations with survival value in nature would become established as ecotypes. Varieties of sorghum of tropical origin are useless in temperate zones and mutations had to occur and be made use of before the species could become useful at latitudes where the species has found its greatest commercial use. There seems every reason to believe that mutations of adaptation genes that control either response to photoperiod and to temperature, or both, are responsible for the existence of varieties of many species that have widespread geographical distribution.

SUMMARY

A study of the inheritance of duration of growth in milo, a grain sorghum group, disclosed that four maturity phenotypes exist that are the result of the action of three genes. Lateness is dominant to earliness, but the second and third genes, Ma_2 and Ma_3, do not express themselves except in the presence of dominant Ma. Also, the third gene, Ma_3, does not express itself in the presence of dominant Ma_2, and on account of these conditions four phenotypes represent all eight genotypes. The four phenotypes for maturity have been designated as Early, Intermediate, Late, and Ultra-late.

The gene Ma was found to be linked with Dw_2, a gene that influences length of internode. The gene Ma_3 was found to be linked with R, a gene that controls presence or absence of a plant pigment.

The action of the gene *Ma* is influenced by photoperiod. When grown under 10-hour photoperiods, the Early, Intermediate, Late, and Ultra-late genotypes of the 14-hour photoperiod were identical in appearance. The genes Ma_2 and Ma_3 were not able to express themselves if the plants were grown under 10-hour photoperiods and not under 14-hour photoperiods unless the gene *Ma* was present in the dominant condition.

Three types of internodal disposition occurred among the four phenotypes for maturity. The Early strain had internodes that increase in length from the ground to the peduncle. The Intermediate strain had a short internode near the top of the plant with longer internodes above and below it. The Late and Ultra-late strains had two areas of constriction, one close to the ground and the other close to the top of the plant.

This study of the inheritance of duration of growth in milo is actually concerned with the time of floral initiation. The time of floral initiation controlled the number of leaves, the duration of growth, and the ultimate size of plant. A difference in two genes that influenced duration of growth was sufficient to bring about a two-fold difference in plant size.

The three genes found to affect maturity date in milo are typical adaptation genes and they determine the range in both latitude and altitude as well as the rainfall belt in which a strain or variety can be grown successfully as a grain crop.

This study leads to the belief that adaptation and normal growth are under control of fewer genes than is generally supposed. Varietal adaptation is explained by these results as well as unequal response of a single variety to different environments. An understanding of the inheritance of these genes and the manifestations produced by them is valuable in a program of crop improvement.

LITERATURE CITED

1. ABBE, ERNEST C., RANDOLPH, L. F., and EINSET, JOHN. The developmental relationship between shoot apex and growth pattern of leaf blade in diploid maize. Amer. Jour. Bot., 28:778–784. 1941.
2. ABEGG, F. A. A genetic factor for the annual habit in beets and linkage relationship. Jour. Agr. Res., 53:493–511. 1936.
3. ALLARD, H. A. Gigantism in nicotinia tabacum and its alternative inheritance. Amer. Nat., 53:218–233. 1919.
4. AYYANGAR, G. N., RANGASWAMI, VIJIARAGHAVAN, C., AYYAR, M. A., SANKARA, and RAO, V. Panduranga. Inheritance of characters in sorghum—the great millet. III. Grain colours: red, yellow, and white. Indian. Jour. Agr. Sci., 3:594–604. 1933.
5. ———, AYYAR, M. A. SANKARA, and NAMBIAR, A. KUNHIKORAN. The inheritance of height cum duration in sorghum. Madras Agr. Jour., 25: 107–118. 1937.
6. BHIDE, R. K. Inheritance and correlation of certain characters in rice crosses. Poona Agr. Col. Mag., 18:76–85. 1926.
7. BORTHWICK, H. A., and PARKER, M. W. Photoperiodic responses of several varieties of soybeans. Bot. Gaz., 101:341–365. 1939.
8. CONNER, A. B., and KARPER, R. E. The inheritance of seed coat color in certain crosses in grain sorghum. Jour. Amer. Soc. Agron., 15:338–344. 1923.
9. EVANS, MORGAN W., and GROVER, FREDERICK O. Developmental morphology of the growing point of the shoot and the inflorescence in grasses. Jour. Agr. Res., 61:481–520. 1940.
10. GARNER, W. W., and ALLARD, H. A. Further studies in photoperiodism, the

response of the plant to relative length of day and night. Jour. Agr. Res., 23:871–920. 1923.

11. GOODWIN, RICHARD H. The inheritance of flowering time in a short day species, Solidago sempervirens L. Genetics, 29:503–519. 1944.
12. GRAHAM, R. J. DOUGLAS. Pollination and cross-fertilization in the Juar plant (*Andropog n Sorghum*, Brot.). India Dept. Agr. Mem., Bot. Ser., 8:201–216. 1916.
13. HAMNER, KARL C. Correlative effects of environmental factors on photoperiodism. Bot. Gaz., 99:615–629. 1938.
14. ————. Hormones and photoperiodism. Cold Springs Harbor Sym. Quan. Biol., 10:49–59. 1942.
15. ————. Photoperiodism in plants. Ann. Rev. of Biochem., 13:575–590. 1944.
16. HECTOR, G. P. Correlation of colour characters in rice. India Dept. Agr. Mem., Bot. Ser., 11:153–183. 1922.
17. KARPER, R. E. A dominant mutation of frequent recurrence in sorghum. Amer. Nat., 66:511–529. 1932.
18. ————. Inheritance in grain sorghum. Tex. Agr. Exp. Sta. Ann. Rpt., 46: 62–64. 1933.
19. ————, QUINBY, J. R., JONES, D. L., and DICKSON, R. E. Grain sorghum date of planting and spacing experiments. Tex. Agr. Exp. Sta. Bul. 424. 1931.
20. ————, ————. Hybrid vigor in sorghum. Jour. Hered., 28:82–91. 1937.
21. LANGHAM, D. G. The inheritance of intergeneric differences in Zea-Euchlaena hybrids. Genetics, 25:88–108. 1940.
22. LITTLE, THOMAS M., and KANTOR, JEROME H. Inheritance of earliness of flowering in the sweet pea. Jour. Hered., 32:379–383. 1941.
23. OWEN, F. V., CARSNER, EUBANKS, and STOUT, MYRON. Photothermal induction of flowering in sugar beets. Jour. Agr. Res., 61:101–124. 1940.
24. POWERS, LE ROY. The nature and interaction of genes differentiating habit of growth in a cross between varieties of Triticum vulgare. Jour. Agr. Res., 49:573–605. 1934.
25. REEVES, R. G., and MANGELSDORF, P. C. A proposed taxonomic change in the tribe Maydeae (family Gramineae). Amer. Jour. Bot., 29:815–817. 1942.
26. SIEGLINGER, JOHN B. Seed-color inheritance in certain grain sorghum crosses. Jour. Agr. Res., 27:53–64. 1924.
27. ————. Inheritance of height in broomcorn. Jour. Agr. Res., 44:13–20. 1932.
28. ————. Leaf number of sorghum stalks. Jour. Amer. Soc. Agron., 28: 636–642. 1936.
29. SINNOTT, E. W. The relationship between body size and organ size in plants. Amer. Nat., 55:385–403. 1921.
30. SMITH, HUGH BURNICE. Annual versus biennial growth habit and its inheritance in *Melilotus alba*. Amer. Jour. Bot., 14:129–146. 1927.
31. SNOWDEN, J. D. The Cultivated Races of Sorghum. London: Adlard and Son, Ltd. 1936.
32. SPRAGUE, GEORGE F. Experiments on iarovizing corn. Jour. Agr. Res., 48: 1113–1120. 1934.
33. STEPHENS, J. C., and QUINBY, J. R. Anthesis, pollination, and fertilization in sorghum. Jour. Agr. Res., 49:123–136. 1934.
34. SWANSON, ARTHUR F. Seed-coat structure and inheritance of seed solor in sorghums. Jour. Agr. Res., 37:577–588. 1928.
35. VINALL, H. N., and CRON, A. B. Improvement of sorghums by hybridization. Jour. Hered., 12:435–443. 1921.
36. VINALL, H. N., STEPHENS, J. C., and MARTIN, J. H. Identification, history and distribution of common sorghum varieties. U.S.D.A. Tech. Bul. 506. 1936.
37. YARNELL, S. H. Influence of the environment on the expression of hereditary factors in relation to plant breeding. Proc. Amer. Soc. Hort. Sci., 41:398–411. 1942.

A NEW WAXY ALLEL IN CORN AND ITS EFFECT ON THE PROPERTIES OF THE ENDOSPERM STARCH[1]

B. BRIMHALL, G. F. SPRAGUE, AND J. E. SASS[2]

WAXY corn was first reported by Collins (6)[3] in 1909. Since that date seven waxy mutations have been reported. In view of the present interest and commercial importance of waxy corn it seemed desirable to examine the effect of these mutations on properties of the endosperm starch.

The waxy mutations reported by Bregger (4) and Mangelsdorf (7) were crossed with the original waxy allel and found to produce waxy seeds in F_1. From this it was concluded that they represented recurrent mutations. At the present time this cannot be considered adequate proof that a new allel was not involved. Unfortunately, these stocks were not maintained and further tests are impossible.

Two additional waxy mutations were discovered by Andrés and Bascialli (1) in the Argentina varieties Colorado Fortin Refugio and Amarillo Fortin Refugio. These were tentatively designated as wx 38a and wx 38b and shown not to be identical with the Chinese wx type. Andrés (2) reports that these two mutations are similar and has assigned to them the symbol wx^A. In this report we are using the symbol wx^a for this same type in conformity with standard genetic nomenclature.

Bear (3) has reported three additional waxy mutations in inbred lines of dent corn. Staining reaction and chemical analysis indicate that these three mutations are indistinguishable from the wx allel reported by Collins. This report is concerned primarily with a study of the effects of the wx^a allel on properties of the endosperm starch.

EXPERIMENTAL METHODS

SOURCE OF SAMPLES

The grain used in these studies was obtained from three sources, Iowa 939, Iowax No. 1, and Argentine waxy. The origin of the Iowax No. 1 was described in a previous publication (10). Using these endosperm types two sets of crosses were made as follows:

1. Iowax No. 1, sib-pollinated........................wx wx wx
   Iowax No. 1 ×Argentine waxy........................wx wx wx^a
   Argentine waxy×Iowax No. 1........................wx^a wx^a wx
   Argentine waxy, sib-pollinated........................wx^a wx^a wx^a
2. Iowa 939, sib-pollinated........................Wx Wx Wx

[1]Contribution from the Plant Chemistry and Farm Crops Subsections and the Botany and Plant Pathology Section, Iowa Agricultural Experiment Station, Ames, Iowa, in cooperation with the Division of Cereal Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture. Journal Paper No. J-1267 of the Iowa Agricultural Experiment Station. Project 616. Supported in part by a grant from the Corn Industries Research Foundation. Received for publication May 19, 1945.

[2]Research Associate, Plant Chemistry Subsection; Senior Agronomist, Division of Cereal Crops and Diseases and Collaborator, Agronomy Section, Farm Crops Subsection, Iowa Agr. Exp. Station; and Associate Professor, Botany and Plant Pathology Section, Iowa Agricultural Experiment Station, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 944.

Iowa 939 × Argentine waxy.................. Wx Wx wx^a
Argentine waxy × Iowa 939 wx^a wx^a Wx
Argentine waxy, sib-pollinated..................... wx^a wx^a wx^a

Each of these samples represented a composite comprising 10 or more ears.

ISOLATION OF STARCH FROM SMALL SAMPLES

The kernels were covered with distilled water and placed in an oven at a temperature of 50° C for 2 to 3 hours. Upon removal, the water was drained off and the kernels hand dissected. After the pericarp was peeled off, the germ was removed and the endosperm dried at 50° C for about 15 hours. This insures that the starch obtained will not be contaminated by blue staining granules from the germ. Forty to 50 grams of the dried endosperms were then ground in a micro-Wiley and finally in a Merker mill to pass a 100-mesh sieve.

The ground corn in 250-ml centrifuge tubes was then treated successively with the following reagents: Two portions of 75% ethanol, for 2 hours; a 0.2% solution of sulfur dioxide, overnight at 50° C; 0.12 N sodium hydroxide solution, for 2 or 3 hours. Upon centrifuging after the latter treatment, a layer of glutinous material formed on top of the centrifuged solids and could be washed off. Centrifuging with distilled water was repeated until a glutinous layer no longer formed, after which the starch was neutralized with HCl, washed, and dried.

Potentiometric iodine titrations for amylose content were carried out as described previously (10), using 0.2-gram samples of defatted starches. Schoch and Williams (9) have noted that removal of the small amount of fatty acids naturally associated with corn starch increased the apparent amylose content from 21 to 22% to 27 to 29%. Consequently, all titration values reported in this paper were obtained on defatted starch samples.

Viscosities were determined at 90° C, using the capillary method. The pastes were buffered at pH 6.0.

EXPERIMENTAL RESULTS

The mutant wx^a occurred in a small-seeded Argentine flint variety.[4] Dr. Andres states in official correspondence that, "The mutation wx38a is characterized by the production of opaqueness and waxiness of the seed, sometime after harvest and only when there is a low humidity content (about 13 per cent). With the pair Wx wx already known, there forms a series of multiple allelomorphs, the order of dominance being Wx, wx 38a, wx." The relationship between moisture content and development of the opaque waxy appearance is also characteristic of the wx allel. We have been unable to distinguish between these two allels on this basis with any high degree of accuracy. However, the two recessive types are clearly distinguishable by other means.

Starch isolated from endosperms of the genotype wx wx wx contain only amylopectin, the branched molecule form which stains red or red-brown with iodine. Starch from the genotype $wx^awx^awx^a$ is predominately amylopectin but contains 2 to 3% of amylose, the straight chain molecule form which stains blue with iodine.

The characteristic iodine reactions of common waxy and non-waxy starch can be obtained in microtome sections of the kernel (8). By immersing the slide in very dilute IKI solution, it is easy to distinguish between the deep blue color of straight chain starch and the yellow-brown of ordinary waxy. The color imparted to Argentine waxy

[4]Seed of wx^a was obtained through the Division of Plant Exploration and Introduction, Bureau of Plant Industry, Soils, and Agricultural Engineering.

starch is a pale orchid-violet. If the concentration of iodine is too great, discrimination is impaired. The dense packing of starch grains in localized regions of the kernel also results in deceptive variations of color in different regions of an overstained kernel. Immersion for 12 hours in 0.1% iodine produces uniform coloration, showing that all granules in a cell, and all regions of the endosperm, contain the same type of starch.

The color obtained in aqueous iodine mounts of milled starch is not as uniform as that obtained in sections of kernels. When milled starch is stained in iodine and cleared in lactophenol, the granules have a uniform, pale violet color. The aqueous iodine preparation is useful for diagnostic purposes, but the cleared microtome sections and the lactophenol preparations of extracted starch afford good evidence of uniformity throughout the endosperm.

The starch distribution pattern in the kernel is known to be well established by the twentieth day after pollination, therefore, only one collection of Argentine waxy kernels was made, 20 days after pollination. A prominent feature of the endosperm of Argentine waxy is the presence of a starch-packed zone at the stylar end (Fig. 1A). This zone is off-center in many kernels (Fig. 1C), and a median section may miss the zone entirely (Fig. 1B). Serial sections of the kernel show that this region is actually a lobe or involution in the endosperm, merging into, and basally continuous with the main body of the endosperm (Fig. 1A, 2A,B).

Cell size and nuclear size are of the same order in the lobe and in the adjacent tissues, and the same type of starch has been demonstrated throughout the endosperm. Both regions are bordered on the distal and radial edges by an aleurone layer one to four cells in thickness, and the interface between the regions obviously consists of infolded aleurone, which merges gradually into the irregular central endosperm (Fig. 2E,F). On the stylar side, the lobe stands out prominently because of its high starch content (Fig. 2C). The contrast on the posterior side is less striking, and the border zone may consist of parenchymatous, rather than aleurone-like cells (Fig. 2 D-F). In addition to the prominent distal lobe, several smaller and less prominent involutions may be present on the perimeter of the endosperm (Fig. 1C).

In an F_2 population derived from the cross wx$\times$wx^a, the kernels can be separated roughly into a 1:2:1 ratio. Such separations have not been checked by F_3 progeny tests and no great accuracy is claimed. Chemical tests are much more precise in characterizing the combinations of these two allels than differential staining.

In previous reports (5,10) it was shown that viscosity measurements and amylose percentages provide excellent means of detecting differences in "degree of waxiness" among starches. These criteria were used to evaluate the differences in starch properties in the two sets of crosses, wx^a$\times$wx and wx^a$\times$Wx.

The data for combinations involving the wx and wx^a allels are presented in Table 1.

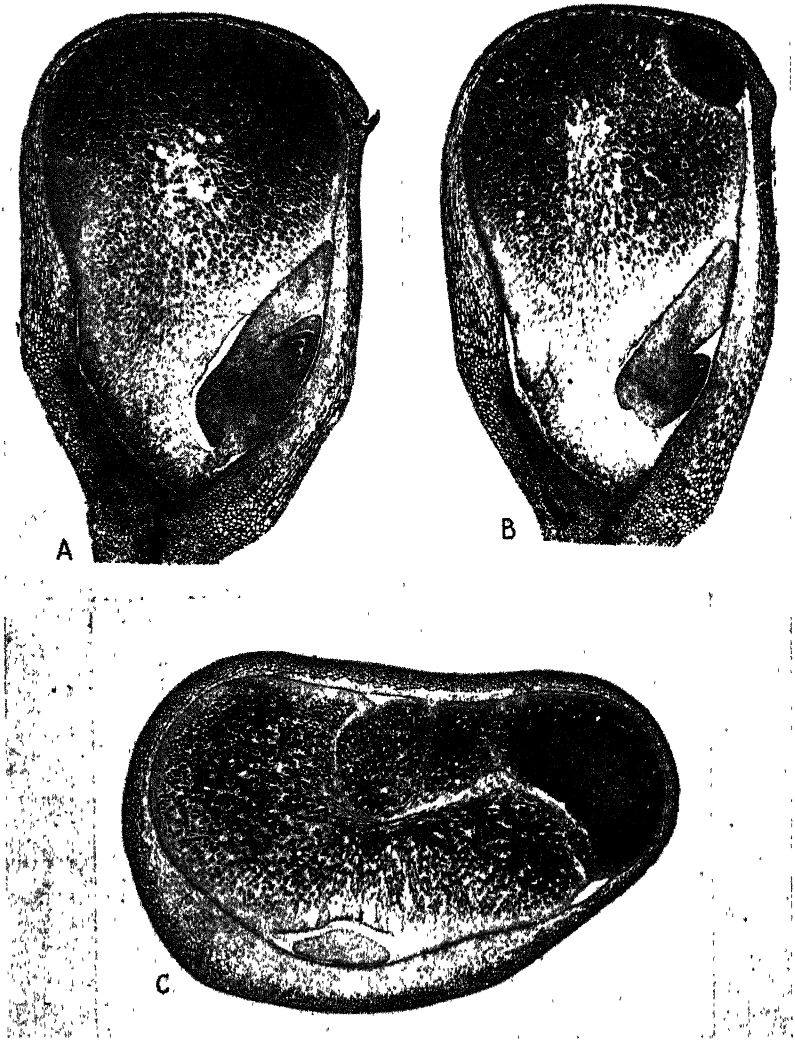

FIG. 1.—Sections of kernels of Argentine waxy maize, 20 days after pollination, 12 X. A, median longitudinal section showing minor involutions in endosperm; B, longitudinal section through lateral edge of plumule, showing apparent "island" at stylar end; C, transverse section near upper end of scutellum, showing several infolutions.

The percentage of amylose is related directly to endosperm genotype and indicates a simple geometric type of gene action. The differences are not great, but they are definite and well differentiated, as shown by the titration curves in Fig. 3. Viscosity is also related directly to genotype and inversely correlated with amylose percentage.

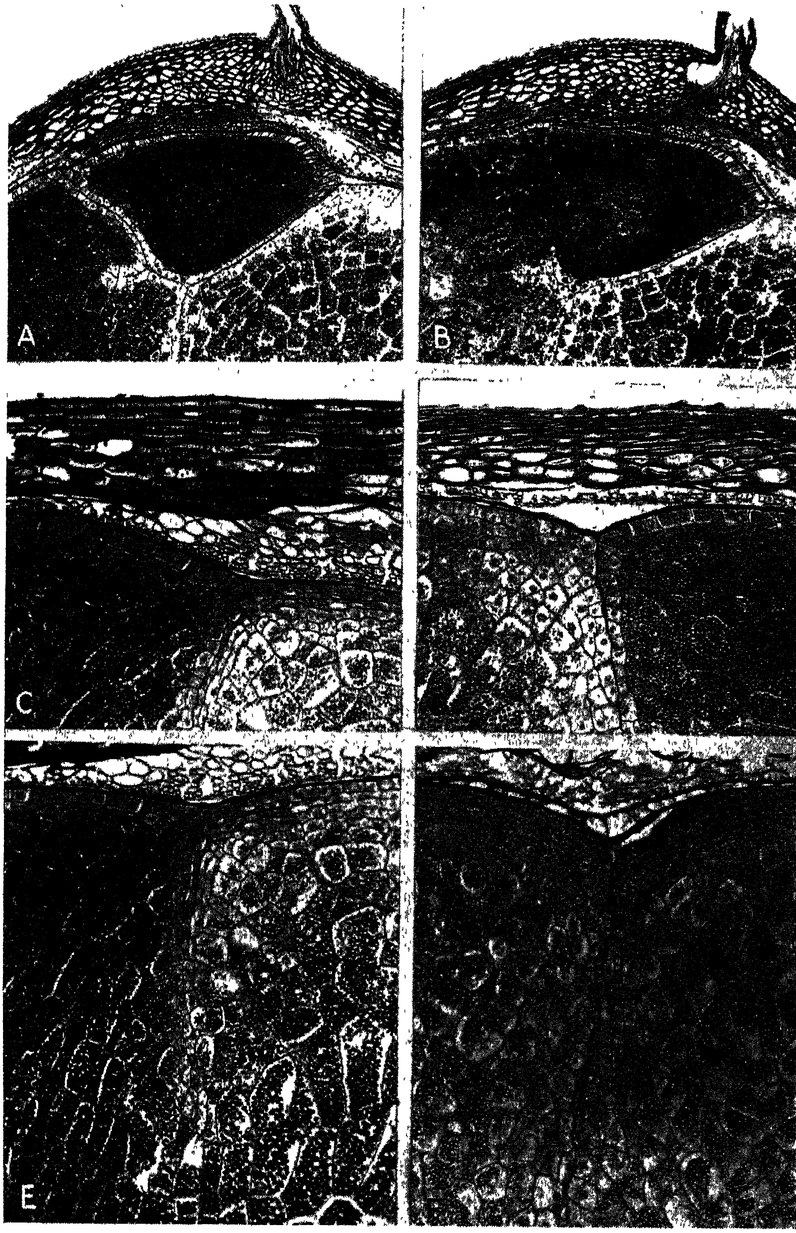

FIG. 2.—Detail of endosperm at distal end of kernel. A, B, serial longitudinal sections 70 μ apart, showing merging of apparent "island" with adjacent endosperm (40×); C, D, sections of two kernels; in each case the dense zone is on the stylar side (80×); E, abrupt termination of involution; F, gradual merging of involuted aleurone into parenchyma.

TABLE 1.—*The relation between endosperm genotype, amylose percentage, and viscosity of the endosperm starch.*

Genotype of endosperm	Amylose percentage	Viscosity seconds (2% paste)
wx wx wx	0.00	65
wx wx wx^a	0.65	60
wx^a wx^a wx	1.30	42
wx^a wx^a wx^a	2.40	31

There is no clear indication of dominance and gene action appears to be additive.

Viscosity and amylose percentage were also determined for direct and reciprocal crosses involving the Wx and wx^a allels. The data are presented in Table 2.

TABLE 2.—*The relation between endosperm genotype, amylose percentage, an viscosity of the endosperm starch.*

Genotype of endosperm	Amylose percentage	Viscosity seconds (2% paste)
Wx Wx Wx	27.7	33
Wx Wx wx^a	27.4	52
wx^a wx^a Wx	26.7	78
wx^a wx^a wx^a	2.4	175

The viscosity of the starch pastes increases with the number of wx^a allels present. This is an agreement with previous data (10) involving a comparable study of Wx and wx allels. The character of

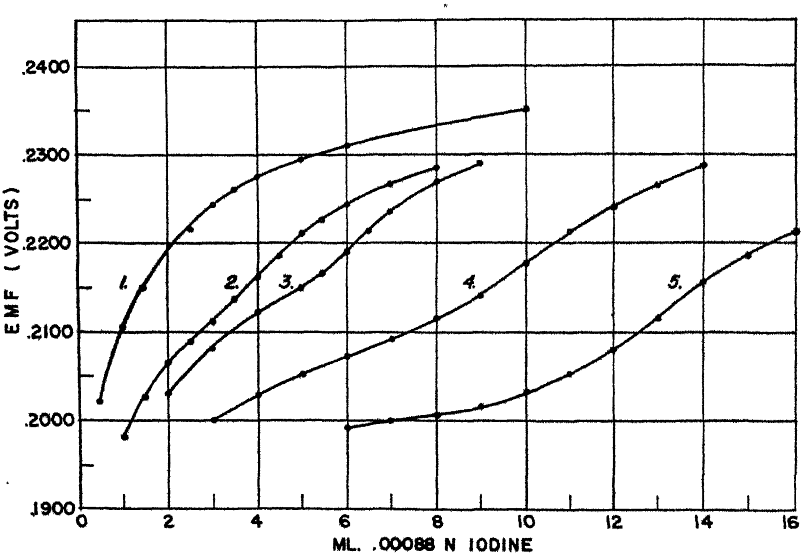

FIG. 3.—Potentiometric titration curves for 0.02% solutions of starches. 1, wx wx wx: 2, wx wx wx^a: 3, wx^a wx^a wx: 4, wx^a wx^a wx^a: 5, waxy barley.

the paste derived from the Wx wx^a wx^a genotype is visibly different than that from Wx Wx Wx, being less opaque and containing many small bubbles characteristic of waxy pastes. On the basis of viscosity measurements gene action appears to be predominantly additive. Amylose percentages, however, indicate a rather high order of dominance of the Wx allel. These results are in general agreement with the results previously reported (10).

DISCUSSION

On the basis of loss of ability to synthesize amylose, this series of multiple allels can be arranged in the order Wx, wx^a, and wx. In this one respect Wx is dominant to both wx^a and wx. However, on the basis of viscosity measurements there is no clear indication of dominance. Considering only the wx^a and wx allels, the variation in amylose percentage suggests a geometric and viscosity measurements an additive type of gene action. Genes which condition several effects, as measured by the end product, are said to be pleitropic. Dominance relations may vary among the series of allels depending on which of the manifold effects is chosen as the basis for classification.

In the present case it appears that an assumption of pleitropism may not be warranted. The three allels Wx, wx^a, and wx effect the general composition and properties of the starch produced. Iodine-staining reaction, amylose percentage, and viscosity measurements are merely different procedures for characterizing starch properties. The apparent pleiotropism may be due entirely to the fact that none of these methods of characterizing starch provides a complete delineation. Viscosity is a logarithmic function of starch concentration, while iodine titration is a linear function. Thus, very small differences in amylose content between Wx Wx wx^a and wx^a wx^a Wx might not be detected by iodine titration but would show up in viscosity determinations.

The waxy cereals studied fall into two general groups. The first group characterized by starch lacking amylose, includes rice, sorghum, and corn (wx wx wx). The second group, characterized by starch possessing a low percentage of amylose, includes barley and corn (wx^a wx^a wx^a). The difference in iodine-staining reaction between waxy barley and other waxy cereals has been noted (10), but a potentiometric iodine titration carried out at that time failed to detect the presence of amylose. This was undoubtedly due to the interference of fatty acids (0.33%) in the barley starch. When this determination was repeated on a defatted sample, 3.5% of amylose was found (Fig. 3).

SUMMARY

1. Analytical data are presented on a waxy mutant (wx^a) which conditions the development of a small percentage of amylose in the endosperm starch.

2. Iodine tests on microtome sections of the kernel show that the starch reaction is uniform throughout the endosperm. The color imparted to the starch is an orchid-violet, distinct from ordinary waxy and from common corn starch.

3. A prominent starch-packed zone commonly occurs in the stylar region of the kernel. This zone is delimited by an involution of the aleurone. Minor involutions may occur lower in the endosperm.

4. In combinations involving the wx^a and wx allels, viscosity measurements indicate arithmetic gene action and percentage of amylose geometric gene action.

5. Gene action in combinations of the Wx and wx^a or Wx and wx allels is arithmetic on the basis of viscosity measurements. In the same combinations amylose percentages indicate a rather high degree of dominance of the Wx allel.

6. The waxy cereals studied may be divided into two general groups; one having no amylose and the second a small percentage of amylose.

LITERATURE CITED

1. ANDRÉS, J. M., and BASCIALLI, P. C. Caracteres hereditarios aislados en maices cultivados en la Argentina. Univ. Buenos Aires Inst. Genetics, 2: 1–26. 1941.
2. ————. Notas sobre genetic del maiz I. Endosperma ceroso en maices argentinos. Univ. Buenos Aires Inst. Genetics, 2:115–121. 1944.
3. BEAR, ROBERT P. Mutations for waxy and sugary endosperm in inbred lines of dent corn. Jour. Amer. Soc. Agron., 36:89–91. 1944.
4. BREGGER, T. Waxy endosperm in Argentine maize. Jour. Hered., 19:111. 1928.
5. BRIMHALL, B., and HIXOM, R. M. The rigidity of starch pastes. Ind. & Eng. Chem., Anal. Ed., 11:358–361. 1939.
6. COLLINS, G. N. A new type of Indian corn from China. U.S.D.A. Bur. Plant Ind. Bul. 161. 1909.
7. MANGELSDORF, P. C. Waxy endosperm in New England maize. Sci., 60: 222–223. 1924.
8. SASS, J. E. Schedules for sectioning maize kernels in paraffin. Stain Tech., 20:93. 1945.
9. SCHOCH, T. J., and WILLIAMS, CARL B. Adsorption of fatty acid by the linear component of corn starch. Jour. Amer. Chem. Soc., 66:1232–33. 1942.
10. SPRAGUE, G. F., BRIMHALL, B., and HIXON, R. M. Some effects of the waxy gene in corn on properties of the endosperm starch. Jour. Amer. Soc. Agron., 35:817–822. 1943.

EFFECT OF CERTAIN CULTURAL PRACTICES ON MOISTURE CONSERVATION ON A PIEDMONT SOIL[1]

EDWIN JAMES[2]

SINCE Wollny's work (26)[3] in 1878, research on soil moisture has been almost continuous. Investigations (1, 4, 9, 10, 11, 12, 14, 15, 19, 20, 21, 25, 26) have demonstrated the limitations of capillary movement of moisture in soils. It has also been shown (2, 5, 6, 7, 8, 13, 17, 23, 24) that under field conditions the soil mulch is relatively ineffective in the conservation of soil moisture. On the other hand, it has been noted (7, 8, 18) that mulches of organic materials are very efficient. In spite of the evidence to the contrary, the impression still exists that the failure of tillage operations to conserve moisture in a given locality has no application to another area where soil conditions are considerably different.

A search of the available literature has revealed no work regarding the effect of tillage operations on the moisture content of southern soils, and this led to the investigation reported herein.

EXPERIMENTAL PROCEDURE

The area selected for the study is typical of the Piedmont section of Georgia. The soil is a heavy phase of Cecil clay loam consisting of a friable brownish-red to red clay loam to heavy clay loam 6 to 8 inches deep, passing abruptly into a subsoil of stiff, brittle red clay that continues without much change to a depth of well below 3 feet. The area has a slope of about 5 to 6%. To isolate the areas under investigation, two trenches were dug, slightly over 20 feet long, 3 feet deep, and 18 inches apart. The trenches were then connected at 4-feet intervals with cross cuts thereby setting up *in situ* four blocks of soil $4 \times 3 \times 1\frac{1}{2}$ feet in dimensions. Only three of the blocks were involved in the study. The other was planted to corn to observe the longevity of corn when no more moisture was added for the rest of the season after the initial saturation.

Plaster paris resistance blocks as developed by Bouyoucos (3) were imbedded diagonally in the face of the sections at depth intervals of 6 inches to a depth of 36 inches. Each section was then wrapped separately with a layer of heavy asphalt roofing material to prevent lateral movement of moisture, and the ditches refilled. Opposite each resistance block, holes were drilled with a soil auger to obtain temperature readings.

The entire area was finally covered with a glass roof about 3 to 4 feet above the soil level and extending far enough over the sides and ends to prevent any rain from falling on the soil.

The roof sloped to the north, thus allowing full insolation under the glass most of the day, and only slightly reduced insolation through the glass for the remainder. The open sides of the glass roof also permitted normal air movement over the surface.

Following the preparation of the area, water was run into each division for several succeeding days until each section was thoroughly saturated. For treatment No. 1, one section was kept free of all vegetation by hand weeding and kept bare for the balance of the investigation. A 2-inch dust mulch was worked up for treatment II and a 2-inch straw mulch applied for treatment III. Area 4 was planted to corn and provided with a 2-inch soil mulch.

When drainage was apparently complete, resistance readings were taken and repeated thereafter 14 times at approximately weekly intervals. The first readings were made on May 6, 1942, and the final ones on September 9, 1942.

[1]Contribution from the Department of Agronomy, University of Georgia, Athens, Ga. Received for publication May 7, 1945.

[2]Associate Professor of Agronomy.

[3]Figures in parenthesis refer to "Literature Cited", p. 951.

RESULTS AND DISCUSSIONS

The moisture percentages derived from the resistance readings are given in Table 1, and graphically in Figs. 1, 2, and 3. Inasmuch as there was no dissimilarity between the percentages at the 6 and 12, 18 and 24, and 30 and 36 inch levels, the curves for the 12, 24, and 30 inch levels are omitted.

It will be noted that the moisture content under the straw mulch remained constant at the 6 and 18 inch levels, but dropped from 26.8% to a final percentage of 22.5 at 36 inches. Much of this can be attributed to drainage. Free water was found at the 30 and 36 inch levels 3 weeks following the first determination. A considerable amount of time would be required for the soil at these depths to reach field capacity. After 66 days the moisture content at 36 inches became practically constant. Moisture equivalents were not determined for samples taken from the different levels. In the laboratory, moisture retention in 10-inch tubes was found to be 14.77, 17.96, 18.25, 28.36, and 28.53 for the 6, 12, 18, 24, 30, and 36 inch levels, respectively. Field capacity would be somewhat under these figures, probably best represented by the moisture content under the straw mulch.

At the 6-inch depth the loss under treatments I and II are practically identical with a maximum difference of 0.7% on the 32nd day. The total loss for the period of the investigation was 4.0% for treatment I and 3.9% for treatment II.

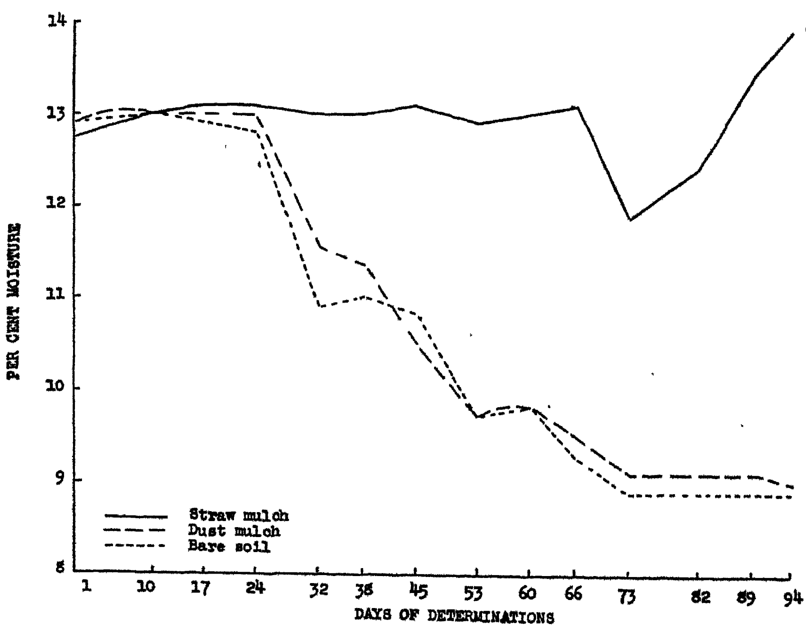

FIG. 1.—Moisture changes at a depth of 6 inches as affected by different treatments.

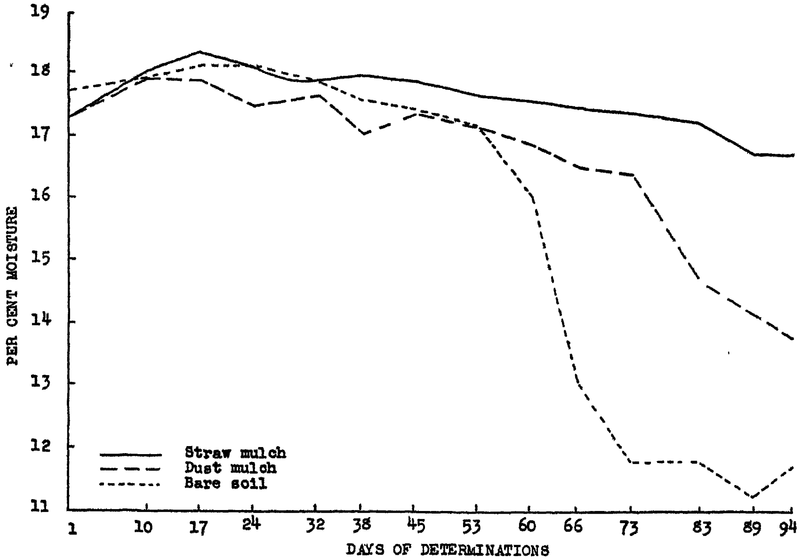

FIG. 2.—Moisture changes at a depth of 18 inches as affected by different treatments.

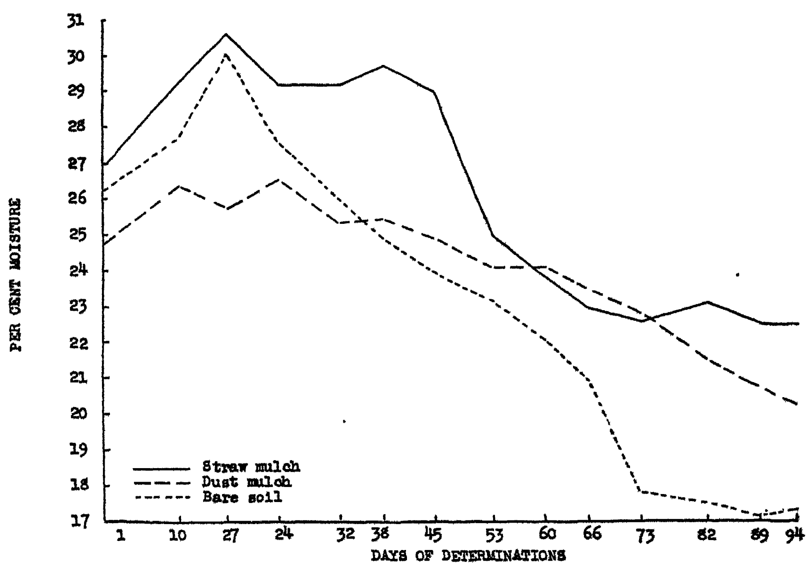

FIG. 3.—Moisture changes at a depth of 36 inches as affected by different treatments.

Accepting the assumption that the final reading of the soil under straw at the 18-inch level was at field capacity, treatments I and II lost 5.1 and 3.0% moisture, respectively, through surface loss. Although the data presented do not lend themselves to statistical inter-

TABLE 1.—*Moisture percentages at various depths under different treatments.*

Determination No.	Day	Depth, inches					
		6	12	18	24	30	36
				I. Bare Soil			
1	1	12.9	12.7	17.7	18.0	28.2	26.2
2	10	13.0	12.7	17.9	19.2	28.7	27.6
3	17	12.9	12.9	18.1	19.2	30.0	30.0
4	24	12.8	12.9	18.1	18.4	30.0	27.6
5	32	10.9	12.9	17.9	18.4	30.0	26.0
6	38	11.0	12.7	17.6	18.0	29.6	24.9
7	45	10.8	12.6	17.5	17.6	29.0	24.0
8	53	9.7	12.0	17.2	17.1	28.3	23.2
9	60	9.8	11.2	16.1	15.8	26.4	22.1
10	66	9.3	10.1	13.1	12.9	24.8	20.9
11	73	8.9	9.5	11.8	12.3	20.0	17.8
12	82	8.9	9.1	11.8	12.1	19.6	17.5
13	89	8.9	9.1	11.3	11.4	19.5	17.1
14	94	8.9	9.2	11.7	12.1	20.1	17.3
				II. Dust Mulch			
1	1	12.9	12.6	17.3	18.0	28.1	24.7
2	10	13.0	13.0	17.9	18.6	28.6	26.3
3	17	13.0	13.0	17.9	19.2	30.0	25.7
4	24	13.0	12.9	17.5	18.2	28.3	26.5
5	32	11.6	13.0	17.7	18.4	26.6	25.3
6	38	11.3	12.7	17.1	18.2	27.7	25.4
7	45	10.5	12.6	17.4	18.0	27.4	24.9
8	53	9.7	12.4	17.2	17.8	26.7	24.1
9	60	9.8	12.2	16.9	17.1	26.7	24.1
10	66	9.5	11.0	16.5	17.3	26.2	23.5
11	73	9.1	10.5	16.4	16.7	25.9	22.8
12	82	9.1	10.4	14.7	14.7	25.0	21.5
13	89	9.1	10.0	14.2	14.1	23.7	20.7
14	94	9.0	9.8	13.8	13.8	22.2	20.2
				III. Straw Mulch			
1	1	12.7	12.7	17.3	17.4	28.3	26.8
2	10	13.0	12.2	18.0	17.3	28.3	29.2
3	17	13.1	12.7	18.3	19.2	30.3	30.6
4	24	13.1	12.9	18.1	19.2	30.2	29.2
5	32	13.0	12.9	17.9	18.6	30.2	29.2
6	38	13.0	12.9	18.0	18.6	30.2	29.7
7	45	13.1	13.1	17.9	18.2	29.7	29.0
8	53	12.9	13.0	17.7	17.8	29.5	25.0
9	60	13.0	12.9	17.6	17.8	29.0	23.8
10	66	13.1	12.8	17.5	17.5	28.3	23.0
11	73	11.8	13.0	17.4	17.4	27.9	22.6
12	82	12.4	12.7	17.3	17.0	27.4	23.1
13	89	13.4	13.5	16.8	17.0	27.0	22.5
14	94	13.9	13.5	16.8	17.0	26.3	22.5

pretation, the small difference of 2.1% does not appear to be large enough to demonstrate that the dust mulch was effective in preventing moisture loss. With a field capacity of 22.5% at the 36-inch level, the surface losses from this depth were 5.2 and 2.3% for treatments I and II, respectively, involving a difference of only 2.9%.

Although some investigations (16, 22) show that some loss of moisture can be accounted for by vaporization, the differences in soil temperatures under the various treatments appear hardly large enough to account for the final differences in moisture content. The differences in temperatures are shown in Table 2 and the means in Fig. 4. The greatest difference in the mean temperatures was 1.7° C at the 6-inch level. The insulating effect of the straw diminished directly with the depth.

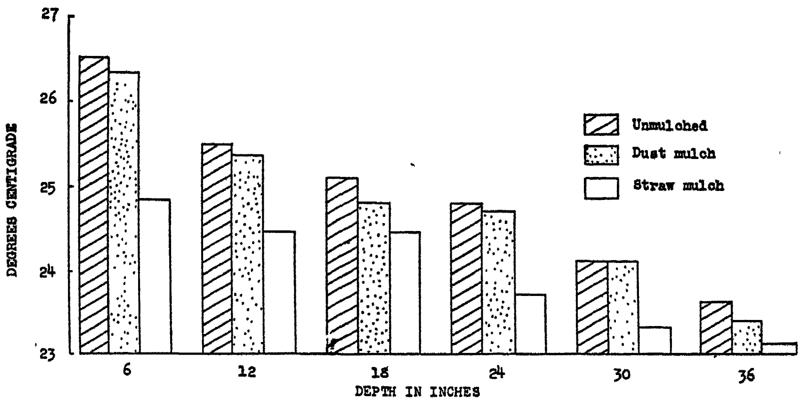

FIG. 4.—Mean soil temperatures as affected by depth and treatment.

In view of the fact that the low moisture content in some southern soils can partially account for low yields of crops, as mentioned previously but not included in the above study, corn was planted in one section.

The time of permanent wilting should have been an indication of the necessary frequency of rains to produce a satisfactory crop. Two plants were permitted to grow on this section and their progress was satisfactory up to 32 days. After this period a visible retardation could be noted. Wilting was first observed on the 60th day and both plants were dead when the reading was taken on the 73rd day. The moisture content when wilting was first observed was 9.9, 11.7, 17.3, 17.1, 26.6, and 24.9% at the levels 6 inches to 36 inches, respectively. When permanent wilting took place the, moisture contents were 9.7, 10.1, 15.9, 16.9, 26.0, and 23.6%, respectively. It would appear that the moisture at the lower levels was not available with sufficient rapidity to the corn, further demonstrating the fact that capillary movement is not rapid enough to meet the needs of a growing crop when the surface moisture is exhausted.

SUMMARY AND CONCLUSIONS

Moisture readings were determined in a Cecil clay soil with a bare surface, a 2-inch mulch, and a 2-inch straw mulch at 6-inch intervals to a depth of 36 inches in blocks $4 \times 1\frac{1}{2} \times 3$ feet, isolated from the surrounding soil and protected from precipitation for the duration of the experiment after initial saturation.

TABLE 2.—*Air and soil temperatures at various depths under different treatments.*

Determination No.	Days	Air temperature, °C	Depth, inches					
			6	12	18	24	30	36
			I. Bare Soil					
1	1	28°	23°	22°	21°	21°	20°	19°
2	10	26°	21°	21°	21°	21°	19°	19°
3	17	24°	20°	20°	20°	20°	20°	19°
4	24	30°	24°	23°	22°	22°	21°	20°
5	32	29°	27°	26°	25°	25°	24°	23°
6	38	31°	25°	24°	24°	24°	24°	24°
7	45	35	30°	27°	27°	27°	26°	25°
8	53	29°	27°	27°	27°	26°	25°	25°
9	60	29°	27°	26°	26°	25°	25°	25°
10	66	32°	32°	29°	28°	27°	26°	26°
11	73	35°	30°	29°	29°	29°	28°	27°
12	82	31°	31°	29°	28°	27°	27°	27°
13	89	31°	30°	29°	28°	28°	26°	26°
14	94	29°	25°	26°	26°	26°	26°	26°
Means...	—	29.9°	26.5°	25.5°	25.1°	24.8°	24.1°	23.6°
			II. Dust Mulch					
1	1	28°	23°	22°	21°	21°	19°	19°
2	10	26°	21°	21°	20°	20°	20°	19°
3	17	24°	21°	20°	20°	20°	20°	19°
4	24	30°	24°	23°	23°	23°	22°	20°
5	32	29°	27°	26°	25°	25°	24°	22°
6	38	31°	25°	24°	25°	24°	24°	23°
7	45	35°	30°	27°	26°	26°	25°	24°
8	53	29°	27°	28°	27°	26°	26°	25°
9	60	29°	27°	26°	26°	26°	26°	25°
10	66	32°	29°	28°	27°	27°	26°	25°
11	73	35°	29°	29°	28°	28°	28°	28°
12	82	31°	30°	28°	27°	27°	27°	26°
13	89	31°	29°	29°	27°	27°	26°	26°
14	94	29°	26°	25°	25°	26°	25°	26°
Means...	—	29.9°	26.3°	25.4°	24.8°	24.7°	24.1°	23.4°
			III. Straw Mulch					
1	1	28°	22°	21°	21°	20°	19°	19°
2	10	26°	20°	20°	20°	19°	19°	19°
3	17	24°	20°	20°	20°	19°	19°	19°
4	24	30°	22°	21°	21°	21°	20°	20°
5	32	29°	25°	24°	24°	23°	22°	22°
6	38	31°	25°	25°	25°	23°	23°	23°
7	45	35°	26°	25°	25°	24°	24°	24°
8	53	28°	26°	26°	26°	26°	25°	25°
9	60	29°	26°	26°	25°	25°	25°	25°
10	66	32°	28°	27°	26°	26°	25°	25°
11	73	35°	28°	28°	28°	27°	27°	27°
12	82	31°	27°	27°	27°	27°	26°	26°
13	89	31°	27°	26°	26°	26°	26°	26°
14	94	29°	26°	25°	26°	26°	26°	24°
Means...	—	29.9°	24.8°	24.4°	24.4°	23.7°	23.3°	23.1°

At the 6-inch level the moisture content of the soil under the straw mulch remained practically constant while that of the bare soil and that under the dust mulch decreased rapidly to the wilting point or below at almost identical rates. At the 18-inch level a somewhat slower decrease was noted for all treatments during the first 8 weeks of the test followed by a rapid loss from the bare soil, a slow loss from the soil under the straw, and an intermediate loss from the soil under the dust mulch. At the 36-inch depth the results were similar to the 18-inch depth, except that the drop in the moisture under all treatments began in the fourth week and continued downward to final percentages of 17.3, 20.2, and 22.5 for the bare soil, dust-mulched soil, and straw-mulched soil, respectively.

Only slight temperature differences were noted between the bare soil and that with the dust mulch, whereas the straw mulch accounted for a maximum difference from the bare soil of 1.7° C.

Satisfactory growth of young corn plants was observed up to 32 days. The corn died when the moisture content in the first 6 inches reached 9.7% and 23.6% at 36 inches, indicating that moisture at a depth of 36 inches in this soil type is not sufficiently available to supply fully the needs of young corn plants.

LITERATURE CITED

1. ALWAY, F. J. Studies on the relation of the nonavailable water of the soil to the hygroscopic coefficient. Nebr. Agr. Exp. Sta. Res. Bul. 3. 1913.
2. ——— and CLARK, V. I. A study of the movement of water in a uniform soil under artificial conditions. Nebr. Agr. Exp. Sta. Ann. Rpt., 1911–12: 246–287. 1912.
3. BOUYOUCOS, G. E., and MICK, A. H. An electrical resistance method for continuous measurement of soil moisture under field conditions. Mich. Agr. Exp. Sta. Tech. Bul. 172. 1941.
4. BRIGGS, L. J., and LAPHAM, M. H. Capillary studies and filtration of clay from soil solutions. U.S.D.A. Bur. of Soils Bul. 19. 1902.
5. CALL, L. E., and SEWELL, M. C. The soil mulch. Jour. Amer. Soc. Agron., 9:49–61. 1917.
6. CHILCOTT, E. C., and HOLM, A. B. Soil Moisture investigations for 1897. S. D. Agr. Exp. Sta. Bul. 58:53–84. 1898.
7. HARRIS, F. S. Movement and distribution of moisture in the soil. Jour. Agr. Res., 10:113–155. 1917.
8. HAYS, W. M., and SMITH, W. G. Cultivation conserves moisture. Minn. Agr. Exp. Sta. Bul. 68. 1900.
9. GAROLA, C. V. Etudes sur L'Ascension capaillare dans les sols. Ann. Sci. Agron. Franc et Etrang, 42:1–32. 1925.
10. KEEN, B. A. Agricultural meteorological work at Rothamstead. Jour. Min. Agr., 33:215–216. 1926.
11. ———. The Evaporation of water from the soil. Jour. Agr. Sci., 6:432–444. 1916.
12. LOUGHRIDGE, R. H. Investigations in soil physics: The capillary rise of water in soils. Col. Agr. Exp. Sta. Ann. Rpt., 1892–1894:91–100. 1894.
13. MOSIER, J. G., and GUSTAFSON, A. F. Soil moisture and tillage for corn. Ill. Agr. Exp. Sta. Bul. 181. 1915.
14. MCLAUGHLIN, W. W. Capillary movement of soil moisture. U.S.D.A. Bul. 835. 1920.
15. PURI, A. W. Physical characteristics of soils: V. The capillary tube hypothesis of soil moisture. Soil Sci., 48:505–520. 1939.
16. PENMAN, H. L. Gas and vapor movements in the soil. Jour. Agr. Sci., 30:437. 1940.
17. ———. Laboratory experiments on evaporation from fallow soil. Jour. Agr. Sci., 31:454. 1941.

18. RUSSELL, J. C. Effect of surface cover on soil moisture losses by evaporation. Soil Sci. Amer. Proc., 4:65-70. 1939.
19. SHAW, C. F. The normal moisture capacity of soils. Soil Sci., 23:303-317. 1927.
20. ——— and SMITH, A. Maximum height of Capillary rise starting with soil at capillary saturation. Hilgardia, 2:399-409. 1927.
21. SHULL, C. A. The measurement of surface forces in the soil. Bot. Gaz., 62. 1-29. 1914.
22. THOMAS, M. C. Aqueous vapor pressure of soils. Soil Sci., 11:409-434. 1921.
23. VEIHEMEYER, F. J. Some factors affecting the irrigation requirements of deciduous orchards. Hilgardia, 2:125-160. 1927.
24. WILLARD, R. E., and HUMBERT, E. P. Soil moisture. N. M. Agr. Exp. Sta. Bul. 86. 1913.
25. WOLLNEY, E. The physical properties of soils. Pt. 2. Exp. Sta. Rec., 6:853. 1895.
26. ZUNKER, F. Das Verholten des Boden zum Wasser. Handbuck der Bodenlehr. Vol. 6.

FIBER CONTENT IN RELATION TO LENGTH AND AGE OF *SANSEVIERIA* THUNB. LEAVES[1]

JULIAN C. CRANE AND RAUL E. ALONSO[2]

THE possibility of using several species belonging to the genus *Sansevieria*, commonly termed *lengua de vaca* (cow tongue) in Latin America, as a source of hard fiber suitable for cordage and bag manufacture has been recognized for many years. The fiber, often referred to as bow-string hemp, has never attained commercial importance, however, due to the lack of technical knowledge regarding the cultural requirements of the plant as well as the problem of fiber extraction from the leaves. During a short period in the early part of this century, three or four small defibering mills were established in various locations in Africa where there were comparatively large areas of *S. Ehrenbergii* Schweinf growing in the wild state. This industry languished according to Wigglesworth (9),[3] however, because of the unsuitability of the fiber as a competitor to sisal and of the fact that the plant, after being cut, produced new leaves very slowly.

The 62 species of the genus *Sansevieria* mentioned in the literature are extraordinarily varied in growth habit and appearance. Some are miniature plants with thick, fleshy leaves a few inches long as contrasted to those which have flat, thin leaves 4 to 6 feet long. Other species are characterized by their single cylindrical leaves in contrast to those which have semi-cylindrical leaves arranged fanlike. There are also aborescent species with leaves arising from a thick stem.

As might be expected, the numerous species native of Africa, according to Greenway (5), are markedly restricted in their habitat. Some grow only in association in extremely desolate country with an annual rainfall of 10 to 20 inches, while others are found in the tropical rainforest with an annual rainfall of 80 inches. Other species are frequently seen growing as the dominate ground cover on coral rock just above the high-water mark and frequently deluged with seawater.

Likewise, as determined at the Imperial Institute (4), the quality of the fiber of the different species varies greatly. On the one extreme is *Sansevieria guineensis* Willd., synonymous to *S. trifaciata* according to Brown (3), with fine, lustrous, strong fibers of even diameter; while on the other is *S. Ehrenbergii* with fibers of marked variation in diameter, those from the interior of the leaf being extremely fine while those from the exterior are very coarse.

---

[1]Joint contribution from the Office of Foreign Agricultural Relations, U. S. Dept. of Agriculture, and the Cuban Agricultural Experiment Station. The collaborative investigations reported here were made possible by funds provided through the Interdepartmental Committee for Cultural and Scientific Cooperation with the American Republics, together with the financial support of the Government of Cuba. Received for publication June 27, 1945.

[2]Associate Agronomist, Office of Foreign Agricultural Relations, U. S. Dept. of Agriculture, and Ingeniero Agronomo, Cuban Agricultural Experiment Station, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 960.

As a result of the increased war-related demand for all types of vegetable fibers and the growing concern of some governments for the development of their natural resources as well as the diversification of their agricultural programs, renewed efforts have been made recently to solve the technical problems of *Sansevieria* fiber production.

The major portion of the literature on *Sansevieria* deals with the taxonomy and botanical description of the various species, while very little has been written on the cultural requirements or technical problems connected with the growing and extraction of the fiber. Any basic information, therefore, on the utilization of this plant for the production of fiber is useful. This paper deals with the results obtained from preliminary investigations conducted on three species of *Sansevieria* at the Cuban Agricultural Experiment Station.

MATERIALS AND METHODS

The predominate species of *Sansevieria* in Cuba is *S. guineensis* with *S. zeylanica* Willd., perhaps, ranking second. Ornamental patches of *S. cylindrica* Bojer and *S. intermedia* Brown also exist but only to a very limited extent.

Before establishing new experimental plantings and initiating cultural investigations with *Sansevieria*, it was considered desirable to determine the relative merits, particularly the yield of fiber, of the three most prevalent species in Cuba. Leaves of *S. guineensis*, *S. zeylanica*, and *S. cylindrica*, about 2 years old and of approximately the same length, were harvested at the Atkins Institution of the Arnold Arboretum at Central Soledad, Cuba. The three species had been planted about the same time and were growing in the woods next to each other under approximately identical environmental conditions. The leaves were transported to the Experiment Station where they were weighed, retted in water, and the yield of fiber determined.

To determine the association between length of leaf and fiber content, a 7- to 8-year-old planting of *Sansevieria guineensis*, growing in rather dense shade in the arboretum at the Cuban Agricultural Experiment Station, was used. The planting was divided into nine plots, each covering an area of 45 square feet and containing about the same stand of plants. The plots were harvested separately by cutting all leaves at ground level with sharp knives. Harvesting of all plots was done during the first week of July 1944. After being harvested, the leaves were taken to the laboratory where they were classified and counted according to length, and each length group was weighed separately. They then were passed through squeeze rollers in order to break the relatively thick epidermal layer and thereby to facilitate the biological retting process. Afterwards they were tied in bundles and submerged in a retting tank for about 15 days. When the fiber came free of pulp and cementing materials, it was thoroughly washed, dried in an oven, and weighed. Samples of leaves from each length group were dried to constant weight in an oven in order to determine the moisture content.

Although length of leaf is a partial criterion with respect to age for about the first two years, after this time all leaves reach their inherent length under a given set of environmental conditions; and a planting of *Sansevieria* may consist of leaves of about the same length but differing in age from 1 to 3 or 4 years.

In order to determine the degree of association between age of leaf and the fiber content, an arbitrary classification was made based on morphological appearance of the leaves. The writers observed that the short basal leaf sheaths of *Sansevieria guineensis* remained green for a period of about a year, after which they turned brown and ceased to function. The dead leaf sheaths generally remained attached to the plant the second year; then they gradually underwent decomposition and were removed from the plant by wind and rain. Three groups of leaves differing in age were set up as follows: Leaves with green basal leaf sheaths, approximately 1 year old; leaves with dried and withered basal leaf sheaths, approximately 2 years old; and leaves with no basal leaf sheaths, more than 2 years old.

Using this classification during harvesting, leaves having approximately the same length but differing with respect to appearance and presence of the basal

leaf sheaths, were selected at random and cut at ground level from another planting of *Sansevieria guineensis*. This planting was growing in the arboretum under slightly different environmental conditions from the one mentioned previously in that it received the morning sunshine. Fiber and moisture determinations were made according to the method stated above.

EXPERIMENTAL RESULTS AND DISCUSSION

Data in Table 1 on the fiber yield of the three main species of *Sansevieria* in Cuba grown under approximately identical environmental conditions show that *S. guineensis* contained 2.67% fiber of the green weight of its leaves as compared to 2.16% and 1.53% for *S. cylindrica* and *S. zeylanica*, respectively. Although *S. cylindrica* produced more fiber per leaf than *S. guineensis*, the former species has been observed to grow considerably slower than the latter and is known to produce fewer leaves per unit of land. Although the average weight per leaf of *S. zeylanica* was 36.5 grams more than the average weight per leaf of *S. guineensis*, it yielded approximately 1% less fiber. Under Cuban conditions, *S. guineensis* appears to be better suited for the production of fiber than either *S. cylindrica* or *S. zeylanica*.

TABLE 1.—*Fiber determinations on samples of Sansevieria guineensis, S. zeylanica and S. cylindrica harvested at Central Soledad, Cuba, each sample composed of 15 leaves about 4 feet long.*

Sample No.	Total green weight, grams	Weight per leaf, grams	Weight of dry fiber, grams	Fiber per leaf, grams	Percentage fiber of green weight
			S. guineensis		
1	2,999	153.26	60.73	4.04	2.64
2	2,086	139.06	56.54	3.76	2.71
Average	2,072	146.16	58.63	3.90	2.67
			S. zeylanica		
1	2,833	188.86	41.99	2.79	1.48
2	2,647	176.46	42.35	2.82	1.59
Average	2,740	182.66	42.17	2.80	1.53
			S. cylindrica		
1	3,578	238.53	76.86	5.12	2.14
2	3,250	216.66	71.43	4.76	2.19
Average	3,414	227.59	74.14	4.94	2.16

The association between length of leaf of *Sansevieria guineensis* and the fiber and moisture content is shown in Fig. 1. With an increase in length of leaf, there was a progressive increase in the percentage fiber content. The fiber content increased from a low of 1.5% in leaves of the shortest group to a high of 2.5% in leaves of the longest group, with the greatest increase occurring in those leaves between the 37- to 48-inch and 49- to 60-inch length groups. The upper

limit of 2.5% lies between the figures presented by Barrett (1), in Porto Rico and Toro (7) in Mexico, who reported the fiber yield to be between 2 and 3% of the green weight of the leaves.

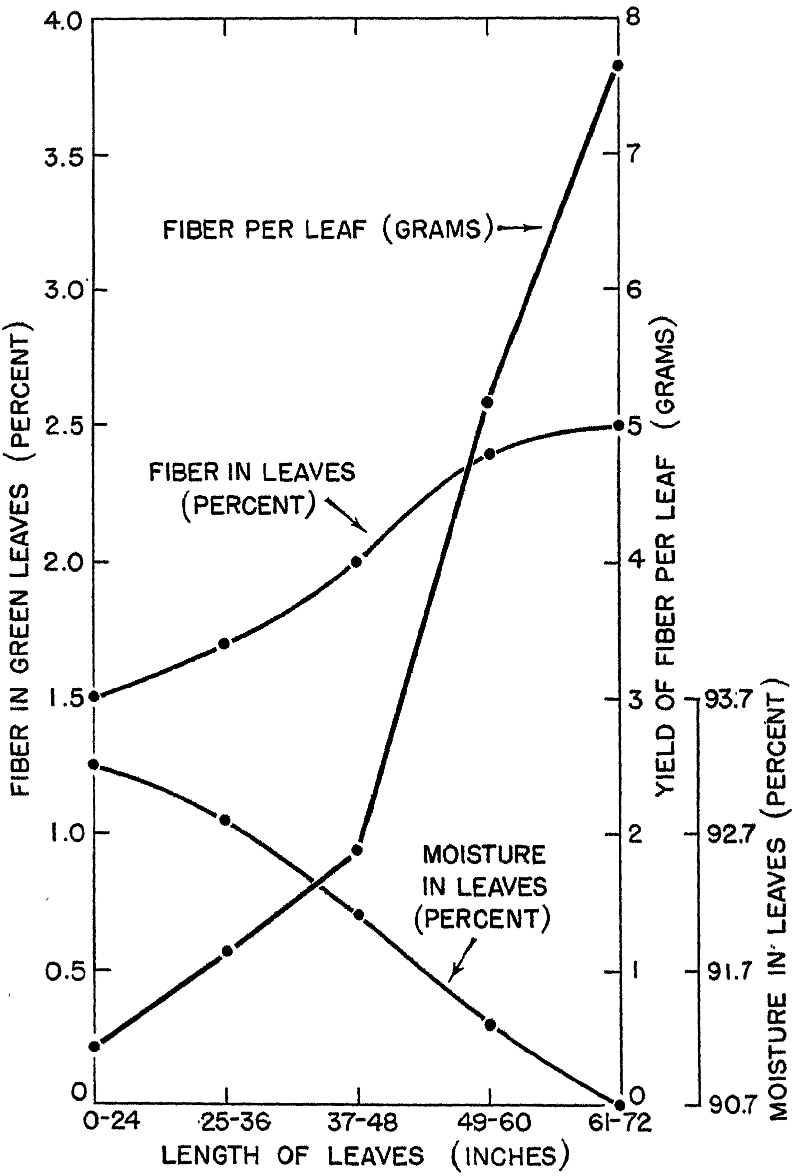

FIG. 1.—Fiber and moisture content in relation to length of *Sansevieria guineensis* leaves.

With this progressive increase in fiber content, there was a slightly greater decrease in the moisture content of the leaves. The moisture content decreased from a high of 93.2% in leaves 0 to 24 inches long to a low of 90.7% in leaves 61 to 72 inches in length. As was expected, the yield of fiber per leaf increased with an increase in leaf length.

The weight of fiber produced per leaf made a gradual increase from 0.44 gram in leaves 0 to 24 inches long to where the leaves were 37 to 48 inches in length followed by a sharp increase to 5.16 grams in leaves 49 to 60 inches long. This rapid increase in fiber produced per leaf is the direct result of a similar increase in the total green weight per leaf as shown in Table 2. From these data it appears that in *S. guineensis*, like other plants, the growth rate during the formative stages is comparatively slow but speeds up during the elongative period and then decreases during maturation. The total weight of dry clean fiber produced per acre from this planting was 3,210 pounds, as shown in Table 2.

Barrett (1), Whitford (8), and Blockman (2) have estimated the yield of fiber per acre to be between 3,000 and 3,500 pounds, while Parsons (6) reported the crop would yield 10,000 pounds of clean fiber per acre. All of the data reported in the literature in regard to

TABLE 2.—*Acre yields of Sansevieria guineensis based on the average production of nine 45 square foot plots, Santiago de las Vegas, Cuba.*

Length of leaves, inches	Number of leaves	Weight of leaves, lbs.	Weight of dry fiber, lbs.	Total green weight per leaf, grams	Percentage of total fiber in each length group
0–24	55,176	3,436	52	28.2	1.62
25–36	176,176	25,526	434	65.7	13.52
37–48	294,272	61,061	1,221	94.1	38.04
49–60	119,064	57,160	1,372	217.8	42.74
61–72	7,744	5,247	131	307.3	4.08
Total	652,432	152,430	3,210	——	100.00

yields of fiber of *Sansevieria* probably are based on estimates made at the discretion of the authors or are the yields obtained from comparatively old undisturbed plantings similar to those used in this investigation for the purpose of determining fiber yield in relation to length and age of leaf and not for the purpose of predicting yields to be expected from commercial plantings. Until a planting of *Sansevieria* on a commercial basis has grown for perhaps 4 or 5 years, doubt exists as to whether, even under optimum conditions, it would produce more than half of the fiber obtained from the planting used in this study. This view point is corroborated by the data presented by Toro (7), who calculated that between 1,338 and 1,695 pounds of dry fiber per acre may be obtained from a commercial planting the third year after it is established. *Sansevieria* is a comparatively slow-growing plant, at least from the standpoint of producing new leaves from the rhizomes; and a minimum of 3 or 4 years would be required for a

new planting to produce 15 leaves per square foot as was the case in this investigation (Fig. 2).

TABLE 3.—*Percentage fiber and moisture in different aged Sansevieria guineensis leaves of about the same length.*

Leaf appearance and approximate age	Green weight, grams	Dry weight, grams	Moisture, %	Dry weight of fiber, grams	Fiber of green weight, %
With green leaf sheaths, 1 year..	1,392	92	93.4	20.88	1.5
With dead leaf sheaths, 2 years	2,984	224	92.5	47.74	1.6
Without leaf sheaths, over 2 years....................	2,482	200	91.9	47.15	1.9

Data presented in Table 3 show that as *Sansevieria guineensis* leaves increased in age, the percentage of fiber likewise increased with an accompanying decrease in moisture. Differences in fiber and moisture percentage data presented in Fig. 1 and Table 3 for separate plantings of the same species, are due, perhaps, to slight differences in environmental conditions under which the two plantings were growing, as mentioned previously. Leaves from the latter plot were harvested following a rainy period which might be responsible for the higher moisture percentage.

Problems such as method and time of harvesting this crop and the resultant effect upon subsequent growth and yield still remain unsolved. Should the practice of cutting all leaves at ground level not prove harmful to the planting, then harvesting may be easily accomplished by using a standard mowing machine with a binder attachment. The belief is, however, that such a severe harvesting method may result over a period of years in the eventful destruction of the planting and, perhaps, the harvesting only of leaves of a given length or longer will have to be resorted to. This will necessitate the design and construction of a machine with an adjustable mechanism for removing the leaves of a desired height, such as 36 inches and longer, which, under the conditions of this experiment, produced approximately 85% of the total fiber obtained as shown in Table 2. A machine of this type might consist of a series of rollers turning in opposite directions and mounted perpendicular to the upright leaves which would, upon contact with the terminal ends of the leaves, break them loose from the underground rhizomes. The point of attachment of the leaves to the rhizome has proved to be the location where the break most generally occurs. Harvesting by this method would consist of removing only the longer leaves while the shorter ones would be left for the next harvest.

From the data presented in Tables 2 and 3, it would appear that for maximum yields of fiber per unit of land, harvesting should be delayed until the leaves are over 2 years old. From an economic standpoint, however, it is questionable whether the increase in yield obtained by delaying harvesting until this time would be profitable. Certainly, time of harvest with respect to age and morphological

FIG. 2.—*Sansevieria guineensis* growing in the arboretum at the Cuban Agricultural Experiment Station. The tallest leaves are about 4 feet in length.

development of the leaves would have a pronounced effect upon the production and growth of new leaves. Another factor which undoubtedly will govern the optimum time for harvesting is the association between fiber quality and age of leaf. The writers have ob-observed that with advancing age of leaf the fiber becomes more coarse and harsh. There is reason to believe that tensile strength and

other factors which make up quality also undergo considerable change.

Environment, particularly in reference to shade, is another factor which will require scientific experimentation before the technical problems of *Sansevieria* fiber production are solved. Although the reports in the literature are quite conflicting in this respect, it is generally agreed that most species of *Sansevieria*, in varying degree, are shade-loving plants, and that better growth and production of leaves is obtained from plants growing in partial or full shade than from plants growing in sunlight.

Defibering trials of this plant, using equipment designed for defibering henequen, have been quite successful in Cuba. Recent experimental trials in Florida, with a somewhat different machine which was designed and built by the U. S. Dept. of Agriculture, have also been encouraging.

SUMMARY

Investigations were conducted at the Cuban Agricultural Experiment Station on *Sansevieria guineensis*, *S. zeylanica*, and *S. cylindrica* to determine the comparative fiber content of their leaves as well as the relationship of fiber content to length and age of *S. guineensis* leaves.

The average fiber content of leaves which had grown under practically identical environmental conditions and were approximately the same length and age was found to be 2.67, 2.16, and 1.53% for *Sansevieria guineensis*, *S. cylindrica*, and *S. zeylanica*, respectively.

With an increase in length of leaf of *Sansevieria guineensis*, there was a progressive increase in the percentage fiber content accompanied by a progressive decrease in the percentage of moisture. Data, based on morphological development of the leaves, are presented which also show that there is an increase in the percentage of fiber accompanied by a decrease in the percentage of moisture.

From a 7- to 8-year-old planting of *Sansevieria guineensis*, 3,210 pounds of dry, clean fiber were produced per acre but, on a commercial basis, doubt exists as to whether more than half of this amount would be produced annually at the end of the fourth or fifth year.

A short discussion is presented dealing with some of the problems which need scientific investigation before the technicalities of *Sansevieria* fiber production are solved.

LITERATURE CITED

1. BARRETT, O. W. Sansevieria. Porto Rico Agr. Exp. Sta. Circ. 1. 1903.
2. BLOCKMAN, L. G. The fibres of the Hawaiian Islands. Occasional Papers, Bernice P. Bishop Museum, 2:37–64. 1903.
3. BROWN, N. E. Sansevieria. A monograph of all the known species. Kew Bul. Misc. Inform. No. 5:185–261. 1915.
4. GOULDING, ERNEST. Textile fibres of vegetable origin; forty years of investigation at the Imperial Institute. Bul. Imp. Inst., 35:27–56. 1937.
5. GREENWAY, P. J. Bowstring hemp or Sansevieria fibre. East African Agr. Jour., 6:96–97. 1941.

6. PARSONS, C. W. The fibre bearing plants of Florida. Savannah, Ga.: The Morning News Print. 1895.
7. TORO, AUGUSTO PEREZ. El cultivo de la Sanseviera en Yucatan. Publicaciones de "Fomento de Yucatan", Merida de Yucatan. 1942.
8. WHITFORD, A. C. Jute and manila fibers. Textile Res., 12:2–7. 1942.
9. WIGGLESWORTH, ALFRED. The hard fibre industry. Jour. Royal Soc. Arts, 79(4087):423–444. 1931.

NOTES

"AGROPYRON JAPONICUM" IS *A. SEMICOSTATUM*

THE writer in a recent issue of this JOURNAL (Vol. 37, pages 319–321) rather too hastily followed Tracy and Scribner in identifying the name *Agropyron japonicum* Tracy with a species of *Brachypodium*. Agnes Chase, Custodian of Grasses, U. S. National Herbarium, has written that since the publication of Hitchcock's *Manual of the Grasses of the United States* in 1935 (page 774), a "Specimen has been found with Vasey's script *'Agropyron Japonicum* V. Cult. in California from New Zealand, originally from Japan. (Collector) E. J. Wickson, Berkeley, Cal. 1888'. A description in Vasey's script is pinned to the sheet. The specimen is *Agropyron semicostatum* Nees. Three more specimens cultivated in Washington, D. C., in 1889 and 1890, one grown by S. M. Tracy, Starkville, Miss., in 1889, 'seed from California', all named '*Agropyron japonicum*', and one grown by A. B. Leckenby, Yakima, Wash., labeled "*Brachypodium japonicum*" are all *A. semicostatum*, and had long ago been distributed in the Old World cover of that species and were overlooked." Also, that "This species has been found on ballast at Portland, Oregon."

Comparison shows the above specimens are the same as the Wickson specimen in the Agronomy Division Herbarium, University of California, Davis, Calif., of which the Wickson photograph was taken.

In addition to Ball (this JOURNAL, Vol. 37, pages 660–661), it is suggested by Chase that the name *Agropyron japonicum* Tracy is at best only a "nomen seminudum" and not sufficiently implemented, in spite of the descriptions and illustration, to invalidate *A. japonicum* Honda. Since only the identification of the names involved is of particular interest to agronomists, a fuller discussion of the point is omitted.—A. A. BEETLE, *Division of Agronomy, University of California, Davis, Calif.*

THE IMPORTANCE OF THE METHOD USED IN WETTING A SOIL[1]

AGRONOMIC research often involves experiments in which different initial soil moisture contents are necessary. The data presented below were obtained from such an experiment. Nichols' method[2] of atomizing water with steam pressure was used to obtain the various moisture levels. The spray was directed on an air-dry sample of Brookston clay which was previously screened through a

[1]Contribution from the Ohio State University and the Ohio Agricultural Experiment Station, Columbus, Ohio.
[2]NICHOLS, M. L. Methods of research in soil dynamics as applied to implement design. Ala. Agr. Exp. Sta. Bul. 229. 1929.

¼-inch sieve. Each sample was stirred carefully by hand during the wetting process. When wetting was completed, the sample was placed in a moisture-proof can for a period of 3 weeks in an attempt to establish equilibrium of the soil moisture. The moisture equivalent and 15 atmosphere-moisture percentage values of this sample were 31.4% and 20.8%, respectively.

The data presented in Table 1 were obtained after compressing three samples of soil having moisture contents of 18.6, 26.3, and 32.6% on the oven-dry basis with pressures ranging from 0 to 20 pounds per square inch. The soil to be compressed was placed in a brass cylinder having a volume of 110.6 cc. A predetermined amount of soil was used such that the final volume would be the same at all pressures after compression. Each sample was then wetted by capillarity, then immersed in water for a period of 24 hours before a tension of 49.0 cms of water was applied. The values in columns 1, 2, and 3 are the percentage moisture remaining in the sample after applying tension by the method of Leamer and Shaw.[3] Each value represents an average of three determinations which agree fairly closely. The initial moisture content of the sample is the average of 24 samples compressed at each moisture level.

TABLE 1.—*The effect of initial wetting and subsequent compression on the moisture retained by Brookston clay at a tension of 49 cms of water.**

Pressure applied to sample, lbs. per square inch	Percentage moisture (dry basis) contained in sample at three initial moisture levels after tension of 49.0 cms water†		
	Level 1	Level 2	Level 3
0	37.1	32.6	27.0
0.5	36.8	32.3	27.5
1	36.9	32.4	26.5
3	36.4	31.7	26.7
5	35.8	31.3	26.4
7	35.4	32.0	26.3
10	35.9	33.1	26.7
20	35.7	34.5	26.6
Average..........	36.2	32.5	26.4

*The initial moisture levels before compression obtained by Nichols' method of wetting were as follows: (1) 32.6%, (2) 26.3%, (3) 18.6%. Each figure represents the average of 24 samples compressed.

†Average percentage moisture of three compressed samples in equilibrium with 49.0 cms water tension.

The data from Table 1 are summarized in Fig. 1A. Observe that the amount of moisture which is retained at a tension of 49.0 cms of water depends upon the initial moisture content of the sample; i.e.,

[3]LEAMER, R. W., and SHAW, BYRON. A simple apparatus for measuring noncapillary porosity on an extensive scale. Jour. Amer. Soc. Agron., 33:1003–1008. 1941.

the lower the initial moisture content, the smaller the amount of water retained. It is also interesting to note that this relationship holds for the range of pressures to which the sample was subjected (Table 1).

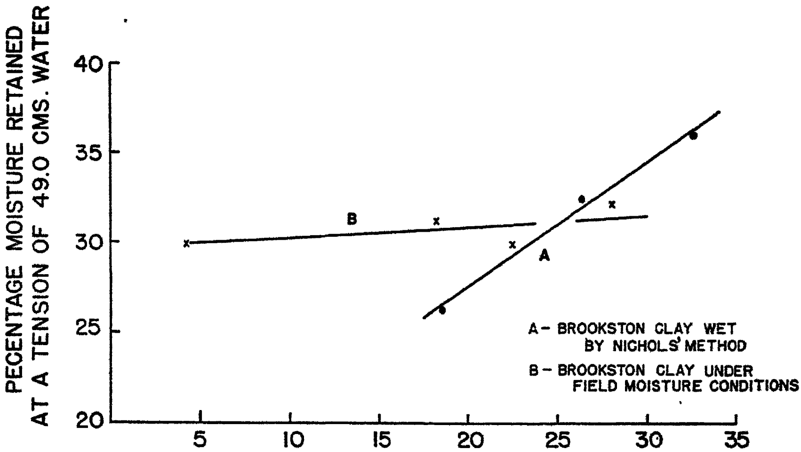

FIG. 1.

Fig. 1B represents four moisture levels of this same soil obtained the following spring by selective sampling in a fall-plowed field of alfalfa. The samples were treated in a manner similar to that above, but only one series of tests were conducted and no pressure was applied. It is seen that the percentage moisture after applying a tension of 49.0 cms water was essentially the same irrespective of the initial field moisture content.

The data presented can only be regarded as tentative since it represents a limited study on one soil type. However, it does seem to indicate that when Nichols' or similar methods are used to wet air-dry soil to various moisture levels, caution should be used in assuming that the type of wetting which occurs is the same as that obtained under natural field conditions.—H. R. HAISE and B. T. SHAW, *Bureau of Plant Industry, Soils, and Agricultural Engineering, U. S. Dept. of Agriculture.*

A METHOD FOR HARVESTING EXPERIMENTAL PLOTS OF CANNERY PEAS[1]

PLOT yields of cannery peas from fertilizer trials, rate of seeding experiments, root rot studies, and similar lines of investigation are usually obtained from plots large enough to provide a sufficient quantity of vines to make the use of a commercial viner feasible.

[1]Contribution from the Division of Vegetable Crops, New York State Agricultural Experimental Station, Geneva, N. Y. Journal Article No. 647.

There are a number of factors connected with this procedure that tend to limit the number of experiments and treatments in any one season. In order to obtain accurate yield data from a commercial viner, approximately 80 to 100 pounds of shelled peas per plot should be vined. To insure this yield per plot due to seasonal fluctuation in yield relatively large plots are required, and a minimum plot size of 1/20 acre would be required if the acre yield of peas for the season were approximately a ton.

Plot size becomes extremely important in the operation of an experiment station where the available area is definitely limited and plot areas of 1/20 acre are, in many cases, out of the question. Occasionally, certain treatment yields must be estimated because there is not sufficient yield from the plot to warrant using the viner. This situation is especially significant when the reduction of yield from root rot is great.

Another serious problem connected with the use of a commercial viner presents itself when the harvesting date of the experimental plots coincide with a rush period at the viner station. It is not an unusual situation to find 30 to 40 truck loads of peas in line waiting to be vined during one of these rush periods. To tie up a viner for a day during this period to harvest small experimental plots can easily become embarrassing both to the cooperating canning company and the experiment station worker conducting the work. Occasionally for this reason the harvesting of experimental plots is either delayed or advanced for too long a time to provide accurate yield data. Finally, this method of harvest is very time consuming when the amount of data obtained is considered.

PROCEDURE

A method of harvesting is proposed that provides a rapid and accurate means for securing plot yields of cannery peas, permits the use of small plot areas of 1/40 acre or less and eliminates the need for a commercial viner. This method is based on the relationship of the weight of shelled peas from a weighed sample of vines from an individual plot. The plot yield is obtained by multiplying the total vine weight of the plot by the ratio of the shelled peas to vines from the sample. For example, if the total weight of vines from the plot is 200 pounds and if 5 pounds of shelled peas are obtained from a 20-pound sample, then the weight of shelled peas per plot is 50 pounds.

The necessary equipment consists of one set of dyanomometer spring scales with capacity 200 pounds $\times$0.5 pound; one set of spring scales, capacity 30 pounds$\times$0.1 pound; tripod, constructed from ½ inch galvanized iron pipe; two canvas ground cloths, 6 by 6 feet, with 4-inch iron rings securely fastened to each corner; a pea huller[2]; and a supply of 2-bushel grain bags.

The vines are cut in the usual manner with a mowing machine equipped with pea harvesting attachments. The total vine weight

[2]This huller was purchased from the Sinclair Scott Company, Baltimore, Md., and is listed as a Junior Pea Huller.

of the plot is obtained by weighing up the vines on the canvas ground cloths attached to the hook of the 200-pound dyanomometer spring scales by means of the iron rings. A representative sample of vines approximating 10% of the total vine weight of the plot is collected in a grain bag, carefully weighed on the 30-pound spring scales, and tagged with the correct plot designation. The pods are removed from this sample by hand and run through the huller. The weight of the shelled peas from the sample is then recorded, using the 30-pound spring scales for this weighing. The total weight of shelled peas from the plot is then secured as indicated above.

ACCURACY OF THE METHOD

The accuracy of the method was checked as follows: Eight lots of peas were taken from two different fields. One of the areas was badly infected with root rot and the other area was located on a slope that had suffered severe erosion and small gulleys formed after planting the peas were still noticeable at harvest time. These areas were purposely taken since the two conditions (presence of root rot and erosion) were conducive to an uneven maturing of peas. It was thought best to test the accuracy of the method under conditions in which nonuniformity in ripening was encountered since it is more difficult to sample an uneven maturing lot of peas than a lot that was maturing evenly especially when small samples are taken. Pods from samples representing 10, 20, 30, and 40% of the total vines from each lot were removed and the yield of shelled peas obtained from each sub-sample. The plot yields were then calculated based on the weight of peas from the various sub-samples. The data are presented in Tables 1 and 2.

TABLE 1.—*A comparison of yields of shelled peas estimated from varying sampling percentages and total yield.*

Sample	Mean yield, pounds per plot*
10%	10.0
20%	10.1
30%	10.1
40%	10.2
100%	10.1

*Average of eight lots.

TABLE 2.—*Analysis of variance of data in Table 1.*

Source of variance	Degrees of freedom	Mean square
Total	39	—
Between lots	7	54.96
Between samples	4	0.07
Error	28	0.071

The data definitely show that no significant differences were obtained between any of the sampling procedures and would indi-

cate 10% of the total vine weight to be an adequate sample to use in estimating the total plot yield.

DISCUSSION

The reliability of this method, as with any other method based on sampling, is largely determined by the degree that the sample is representative of the plot and extreme care should be exercised in obtaining a reliable sample. The huller was found to be very satisfactory for shelling the pods. The time required for harvesting is of interest. Three persons work efficiently in sampling and weighing up the vines. Twelve plots per hour can easily be sampled and weighed. Depending on the individual, the pods from a 20-pound sample of vines can be removed within 20 to 30 minutes. Girls of high school age were found to be satisfactory for this operation. Three to four minutes per sample are required for hulling the pods. The shelled peas can be used for obtaining sample grades and tenderometer readings.

The method can be used on weedy plots as long as a representative sample of weeds and vines is taken from the plot.

The method of harvest offers a number of advantages over the present system of using a commercial viner. Included in these advantages are: (1) A saving of labor; (2) the use of plots of 1/40 acre or less; (3) a doubling or tripling of the number of treatments in the research program for peas without additional labor; (4) the facilitating of work in outlying fields in that vines from the small plots do not have to be transported to the viner station; (5) prevention of the tie up of a commercial viner during the rush season; (6) the sample needs only to approximate 10% of the total vine weight of the plot; (7) samples do not have to be shelled the same day as harvested and can be conveniently stored in a cold room (55° F) from 2 to 3 days after harvest if necessary; (8) the same method appears suitable for obtaining yields of lima bean plots, providing the beans were harvested at the proper stage of maturity.—JOHN F. DAVIS, *New York State Agricultural Experiment Station, Geneva, N. Y.*

AGRONOMIC AFFAIRS

NEWS ITEMS

HOWARD V. JORDAN of the U. S. Dept. of Agriculture, Bureau of Plant Industry, Soils, and Agricultural Engineering, has been transferred to the Mississippi Agricultural Experiment Station, State College, Miss., where he will work cooperatively with that station in soil fertility investigations. He was formerly located at Madison, Wis., where he was engaged in cooperative research with the Wisconsin Agricultural Experiment Station on studies with American hemp.

—A—

DOCTOR L. O. FINE received his discharge from the Navy in September and has returned to his duties as Assistant Agronomist at the Arkansas Agricultural Experiment Station.

—A—

M. M. KEIM, for the past three years industrial specialist with the Chemical Bureau of the War Production Board, has joined the staff of the American Potash Institute. A native Nebraskan, Mr. Keim received his training at the University of Nebraska and his Master's Degree from Rutgers University. With the Potash Institute, he will be in charge of its economic and statistical department.

—A—

DOCTOR A. M. SCHLEHUBER began his duties in October with the Oklahoma Agricultural Experiment Station, Stillwater, Okla., as Agronomist in charge of small grain investigations. This work will be in cooperation with the Division of Cereal Crops and Diseases, Bureau of Plant Industry, Soils and Agricultural Engineering, U. S. Dept. of Agriculture. For the past four years Dr. Schlehuber was employed by the Division of Sugar Plant Investigations of the Department near Meridian, Miss., working on the breeding and genetics of sugar and/or sirup-types of sorgas.

—A—

DOCTOR FRANS VERDOORN, Editor of *Chronica Botanica* and Botanical Adviser to the Board for the Netherlands Indies, writes that, according to reports received from Holland, Australia, and Java, the scientific institutions in the Buitenzorg area (west Java) are relatively in good condition. The classic collections in the herbarium, as well as the grounds of the famous botanic gardens at Buitenzorg, have not been damaged to any considerable extent (it also seems that herbarium material has not been transferred to Japan). The rich library of the Department of Economic Affairs and most of the experiment station buildings are also intact. The following may be quoted from a letter from Dr. C. G. G. J. van Steenis, the well-known authority on Malaysian botany, just received in the United States, "I lost altogether one year-work, but worked harder than in any other period ... finished several papers, and am almost ready

with my cyclopaedia of botanical collectors, and book on Malaysian plant life... Was released as a prisoner of war, August 11, 1942, again in jail, December 14, 1942 to April 13, 1943, worked again to August 13, 1945. Now again interned... The biologists Dr. W. K. Huitema, Ir. P. N. Hackenberg, Dr. J. H. G. Ferman, Dr. M. P. Both, Ir. C. van der Giessen, and P. van der Groot have died. Of many others, especially Dr. M. A. Dork, Dr. P. J. Eyma, and T. H. van den Honert, not yet any news. Dr. O. Posthumus, H. C. D. de Wit, and my wife still working. Hope to be released soon...".

—A—

JOHN L. RETZER, Senior Soil Scientist formerly with the Bureau of Plant Industry, Division of Soils, in California has been transferred to the Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado, where he will conduct research in soils as related to forest and range production.

JOURNAL

OF THE

American Society of Agronomy

VOL. 37 DECEMBER, 1945 NO. 12

EFFECT OF PLANT SPACING AND TIME OF PLANTING ON SEED YIELD OF KENAF, *HIBISCUS CANNABINUS* L.[1]

JULIAN C. CRANE AND JULIÁN B. ACUÑA[2]

KENAF is the name used to signify both the tall annual plant with large showy flowers characteristic of the Mallow family and the bast fiber obtained from the stem of that plant. During the past two or three years when fear has existed that the Japanese might invade India and thereby deprive the Allies of supplies of jute fiber, the kenaf plant has attracted wide attention and undergone considerable investigation. Interest in this plant has resulted from the similarity between jute and kenaf fiber and from the comparatively large yields of the latter which can be produced per unit of land in a short period of time. Yields of over a ton of dried fiber per acre can be produced in from 3 to 4 months on good soils with favorable climatic conditions.

This plant has been cultivated widely in India and at one time was reported (4)[3] to have been used for local consumption in larger quantities than jute. Kenaf fiber has rapidly become a product of commercial importance in Russia where much progress has been made towards determining the cultural requirements of the plant, developing methods of extracting the fiber, and adapting processes for spinning and weaving the fiber (6). In addition kenaf has been used for local consumption in such countries as Java, Persia, Nigeria, Natal, and Egypt.

Kenaf is an herbaceous annual plant which matures its seeds in from 4 to 8 months, depending upon the time of planting. The crop, therefore, must be planted each year as is done in the case of hemp or flax. As the plants are harvested for fiber before or during blossoming and a seed crop, consequently, cannot be harvested from a fiber

[1]Contribution from the Office of Foreign Agricultural Relations, U. S. Dept. of Agriculture, and the Department of Botany, Cuban Agricultural Experiment Station. The collaborative investigations reported here were made possible by funds provided through the U. S. Inter-Departmental Committee for cooperation with the American Republics, together with the financial support of the Government of Cuba. Received for publication January 20, 1945.

[2]Associate Agronomist, Office of Foreign Agricultural Relations, U. S. Dept. of Agriculture, and Head, Department of Botany, Cuban Agricultural Experiment Station, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 977.

planting, a separate planting must be made for seed to be used in planting for fiber the following year.

To determine the effect of plant-spacing and time of planting upon seed production, the following investigation was conducted at the Cuban Agricultural Experiment Station. Although the data presented are the results of only 1 year's investigation, they may serve as preliminary information for persons contemplating the production of this crop until the results of future investigations suggest possible modifications.

REVIEW OF LITERATURE

The literature contains considerable material on the cultivation of kenaf and the uses and properties of its fiber, but the major part of this material is not supported by scientific experimentation and in few cases are clear-cut recommendations given. With a few exceptions, the papers are based on observations on small plantings and data were not collected; and the estimates were made at the discretion of the authors. The recommendations in the literature as to the best planting distance and time of planting for seed production have varied considerably, depending upon the country or location. Likewise, the yields of seed reported being obtained from a given area of land have been extremely divergent.

The differences in time of planting and yield of seed which are found in the literature are to be expected, however, in view of the fact that the kenaf plant is extremely sensitive to changes in length of day. The best time for planting in a location of a given latitude might not be successful in another location of a different latitude. Then again, the most suitable time of planting for fiber in one location might possibly be the best time of planting for seed in another location depending upon latitude. The response of the kenaf plant to length of day will be discussed later on in this paper.

A report by Acuña, *et al.* (1), containing observations on kenaf plantings in El Salvador, states that for seed production the rows should be 20 to 24 inches apart with a distance of 1 foot or more between plants in the row. Plantings made in this manner were estimated to yield between 1,200 and 1,500 pounds of seed per acre. Seed yields were reported to vary according to the time of planting. Smaller yields were obtained from plantings made in September than from those made in May.

Although Dekker (3), in Java, does not mention the best time of planting, he does state that for seed production the plants should be spaced 30 to 40 inches on a square. Yields of seed from plantings of this nature are not mentioned.

Oliveira (5), in Brazil, states that planting should be done between the middle of August and the middle of December. The distance used between plants depends upon the method of seeding employed. When planting was done by hand, three seeds were dropped in each hill 30 by 30 cms (about 12 by 12 inches). However, when mechanical seeders were used, planting was done in continuous rows with a distance between rows of from 20 to 30 cms (8 to 12 inches). Planting at this distance and time of year resulted in yields of only 180 pounds of seed per acre.

A more recent report by Choussy (2), in El Salvador, states that kenaf for seed production should be planted between the middle of August and the last of September due to the fact that environmental conditions during and after that period are much better than conditions throughout the remainder of the year. By planting at that time, it is stated, the plants receive sufficient rainfall over a period of 2 months or more and at the same time the day length becomes short enough to induce flowering 60 to 70 days after planting. The seed-ripening process, which requires from 4 to 5 weeks of dry weather after blossoming, then comes during a period when the rainy season has ceased.

Choussy recommends a planting distance of 0.8 meter (approximately 32 inches) between rows and 25 cms (approximately 10 inches) between plants in the row. He notes that this planting distance is sufficient to obtain branched plants which, he states, produce a larger quantity of seed pods than do plants having

a single stem. Under normal conditions in El Salvador and in plantings which had been well cared for, Choussy estimated the seed yield to be between 700 and 800 pounds per acre.

EXPERIMENTAL METHODS

This investigation was conducted on a Matanzas clay soil which was in a rather low state of fertility. Determinations on representative samples showed the soil had a pH of 6.8, while phosphorus and potassium were present in abundant quantities. The nitrate nitrogen content, however, was very low, and there was no doubt that growth and production of seed was restricted due to this deficiency. Rather severe infestation of the plants with nematodes in some plots also curtailed growth and production of seed.

The land was plowed and cross-plowed to a depth of 8 or 10 inches and was then harrowed several times. A planting was made on July 10, another on August 21, and a third on August 24. The first two plantings consisted of four randomized plant-spacing treatments which were replicated four times. In other words, each of the four blocks of a given planting date contained the following four randomized treatments: 20 inches between rows and 12 inches between hills, 24 inches between rows and 14 inches between hills, 30 inches between rows and 15 inches between hills, and 30 inches between rows and 30 inches between hills.

Several seeds were dropped in each hill and after germination the plants were thinned to the desired number. Although two plants were left per hill in the July 10 planting, it was decided that this was not a sufficient plant population for maximum seed yield and, therefore, thinning was done to three plants per hill in the August 21 planting. The August 24 planting was made with 20 inches between rows with 1½ inches between plants in the row and was intended to be used for fiber purposes only. When these plants had reached maturity, however, it was evident that planting in this manner had resulted in much larger yields of seed per unit of land than planting at greater distances between plants. Several representative samples were harvested and, as a basis of comparison, data collected on these plants are presented with data collected from the other two plantings.

Growth records on 10 random plants in each spacing replication were taken periodically throughout the growing season and at seed maturity 80 representative plants of each treatment were measured and the seed capsules were counted to determine the effect of time and distance of planting on plant development and seed production. When the plants were mature and had shed their leaves, they were cut and the seed was threshed, winnowed, and weighed.

RESULTS

After the plantings had become well established, they were composed of two different varieties of kenaf, both having been named and described by Howard and Howard (4) in India. Nineteen per cent of the plants were of the variety *viridis* with cordate leaves up the entire length of the stem, while the remaining 81% were of the variety *vulgaris* with cordate leaves at the bottom of the plant, 3-, 5-, and 7-palmately lobed leaves respectively up the middle, and 3-palmately lobed leaves on the top portion. Howard and Howard found that *viridis* had a strong tendency to throw out from the base numerous stout branches which grew parallel to the main stem, while in *vulgaris* this tendency was not so pronounced.

Choussy (2) intimated that distance of planting had considerable influence on the degree of branching in these varieties as he stated that distances of 0.5 to 0.8 meter (20 to 32 inches) between plants were sufficient to obtain branched plants which produced a larger quantity of seed capsules than plants which had only single stems.

Under the conditions of this investigation, as is shown by the data in Table 1, however, plant-spacing and time of planting had little

TABLE 1.—*Effect of plant spacing and time of planting on the degree of branching of two varieties of kenaf.*

Planting distance, inches	Percentage of plants within each variety that branched		Total percentage branching in each treatment
	Vulgaris	*Viridis*	
Planted July 10			
20 × 12	5.30	3.19	4.92
24 × 14	6.24	6.45	6.34
30 × 15	5.94	7.93	6.31
30 × 30	6.89	8.49	7.19
Average	6.09	6.51	
Planted Aug. 21			
20 × 12	4.26	3.85	3.86
24 × 14	4.89	4.93	4.43
30 × 15	5.24	4.92	4.81
30 × 30	5.83	6.45	6.13
Average	5.05	5.03	—

influence on the degree of branching which took place. There was also very little difference in the degree of branching between the two varieties, this difference being only 0.42% in the July 10 planting and 0.02% in the August 21 planting. There was a tendency for an increase in the amount of branching with an increase in planting distance. This tendency was more pronounced with *viridis* than with *vulgaris*. The total amount of branching in the two plantings was practically negligible in that of all the plants of a given planting date only 1.49% branched in the July 10 planting while 1.37% branched in the August 21 planting.

Kenaf is a plant which is highly sensitive to changes in length of day. Time of planting for seed or fiber production, therefore, is one of the most important factors in its production. Data presented in Table 2 clearly show this plant's response to time and distance of planting. The average length of the stems without seed capsules or the distance from ground level to the point of attachment of the first seed capsule in the July planting was $4.80 \pm .55$ feet, whereas the corresponding distance for the August planting was $3.63 \pm .16$ feet. The average length of stem with seed capsules or the distance from the point of attachment of the first capsule to the top of the plant was $1.98 \pm .29$ and $2.19 \pm .24$ feet, respectively, in the July and August plantings.

These data show that, irrespective of time of planting, the plants began blooming at approximately the same time. The July planting had more than a month longer for vegetative development than did the August planting before the day length became sufficiently short enough to induce flowering. The plants, consequently, were approximately a foot taller before blossoming started. Although the average length of stems with seed capsules was about the same for both

TABLE 2.—*Plant growth as affected by time and distance of planting, each figure representing 80 plants selected at random.*

Planting distance, inches	Length of stem, feet			Number of seed capsules per plant
	Without seed capsules	With seed capsules	Total	
		Planted July 10		
20 × 12	4.68±.69	1.71±.35	6.39±.99	11.2±3.4
24 × 14	4.87±.69	1.87±.14	6.74±.80	12.7±2.8
30 × 15	4.94±.55	1.88±.34	6.82±.23	13.4±2.2
30 × 30	4.74±.28	2.48±.34	7.22±.32	17.8±3.6
Average	4.80±.55	1.98±.29	6.79±.58	13.7±3.0
		Planted Aug. 21		
20 × 12	3.74±.18	1.81±.21	5.55±.35	8.8±3.4
24 × 14	3.62±.12	2.21±.35	5.84±.28	9.6±2.3
30 × 15	3.67±.18	2.01±.16	5.68±.23	9.8±1.4
30 × 30	3.50±.16	2.75±.26	6.26±.40	15.4±4.4
Average	3.63±.16	2.19±.24	5.83±.31	10.9±2.8
		Planted Aug. 24		
20 × 1½	3.95±.39	1.41±.39	5.36±.22	7.0±1.3

planting dates, the average number of seed capsules per plant was considerably lower in the August planting than in the July planting. This difference was not entirely due to the greater stand of plants in the August 21 planting than in the July 10 planting, thereby resulting in a smaller amount of plant nutrients available per plant for growth and production of seed, because plants which were planted 30×15 inches in the August 21 planting, even though they had a larger feeding area per plant, yielded less than plants spaced 24×14 inches in the July 10 planting. This reduction in the number of seed capsules per plant in the August 21 planting is attributed to time of planting and the subsequent changes in length of day. On the other hand, the response to competition among plants is demonstrated by comparing the average number of seed capsules per plant in the August 21 planting with the average number of seed capsules per plant in the August 24 planting made only 4 days later. The plant population in the latter planting was sufficiently dense to restrict somewhat seed development of the individual plants.

The effect of plant spacing on vegetative and seed development of kenaf was the same that has been observed in practically all other plants, that is, with an increase in the distance between plants there was a tendency for a progressive increase in the size of the plants and an increase in the number of seed capsules per plant.

Data presented in Table 3 show the resulting number of plants per acre by planting at five different rates as well as the effect of these planting distances and time of planting on subsequent yields of seed. It will be noted that there was a pronounced tendency for an in-

crease in production of seed per plant with an increase in planting distance, but at the same time there was a progressive decrease in yield of seed per acre. Although the seed yield per plant at the widest spacing, both in the July and August plantings, was twice as large as the seed yield per plant at the narrowest spacing, this difference was not great enough to compensate for the much larger number of plants per acre in plantings of the narrowest spacing. These data also show that the yield of seed per plant became progressively smaller as plantings were made later in the season. Plants in the August 21 planting yielded approximately 1 gram, or 26%, less seed per plant than plants in the July 10 planting. This decrease in yield was not caused by increased competition among plants in the August 21 planting as a result of a larger plant population per area of land because, for example, plants which were planted three plants to a hill spaced 30×15 inches in the August 21 planting yielded less per plant than did two plants per hill spaced 20×12 inches or 24×14 inches in the July 10 planting, even though they had a larger area per plant to feed from. On the other hand, this decrease in yield per plant is attributed directly to the time of planting and the period following for vegetative and seed development in which changes in environmental conditions occurred.

TABLE 3.—*Effect of time and distance of planting on yield of seed of kenaf.*

Planting distance, inches	Seed per plant, grams	Seed per acre, lbs.	Plants per acre
	Planted July 10 (Harvested Dec. 2)		
20 × 12	4.28±1.99	507±236	53,767
24 × 14	5.52±1.70	469±144	38,581
30 × 15	5.32±1.50	339± 95	28,873
30 × 30	8.10±2.37	267± 78	14,935
Average	5.80±1.89	395±138	34,039
	Planted Aug. 21 (Harvested Dec. 29)*		
20 × 12	3.36± .92	597±164	80,651
24 × 14	4.17±1.00	532±128	57,873
30 × 15	3.89± .44	371± 42	43,311
30 × 30	6.94±1.98	343± 98	22,402
Average	4.59±1.08	460±108	51,059
	Planted Aug. 24 (Harvested Dec. 29)*		
20 × 1½	3.14± .73	1,527±353	219,551

*These plots could have been harvested 2 weeks earlier but time and facilities were not available.

Although the different plots in the August 21 planting had over 33% more plants than similar plots in the July 10 planting, average acre yields of only 16% more seed were produced than these plots. By increasing the number of plants to 219,551 per acre, as was done in the August 24 planting, yields of 1,527 pounds of seed per acre were obtained. It logically follows that much larger yields can be obtained by planting in July when the yield per plant is highest, using

the distance of planting that was employed in this investigation for the August 24 planting.

DISCUSSION AND CONCLUSIONS

The data presented in Tables 2 and 3 indicate readily that the time and distance of planting had a decided influence on the yield of seed of this plant. Of these two factors, time of planting is, perhaps, more important than distance of planting as it determines whether the crop will be a success or failure. If planting is done at a time when the day length is sufficiently short to induce blossoming, the plants begin flowering when only 1 to 2 feet in height and relatively small yields of seed are produced. Likewise, if a dry period of 4 or 5 weeks does not follow blossoming, the seeds germinate in the capsules before they can be harvested. For seed production, kenaf must be planted at a time when there is sufficient rainfall throughout a period of 2 or 3 months followed by a dry period in which the seeds can mature and ripen.

Along with the special requirement of climate, there is another factor which is of prime importance inasmuch as the kenaf plant is photoperiodic and is influenced markedly by changes in length of the daily light period. This plant will not flower in Cuba until the length of the daily light period is shortened to approximately 12½ hours or less. A 12½-hour day length does not occur at this latitude (23° North) until the first part of September. Regardless of the time of planting, throughout the months from April to August, consequently, blossoming will not take place until September or October. This phenomenon is demonstrated in Fig. 1. Although the August 21 and 24 plantings were made 43 and 46 days, respectively, after the July 10 planting, the period of blossoming was practically identical for the three plantings.

As the rainy season in Cuba generally ends about the last of October (Fig. 1) and as the day length is short enough to induce flowering during the months of September and October, the most reasonable time of planting for seed is during the months of July and August. The yield data presented in Table 3 show that higher yields of seed per plant were obtained from the July planting than from the August planting. It would appear, therefore, that for maximum yields of seed, planting should be done in July. Planting at this time, however, allows for approximately 2 months of vegetative development before flowering takes place; and, as a result, the bottom 5- or 6-foot portions of the stems are barren and contain no seed capsules. As plantings are made progressively later in the season, the portion of the stem which is barren becomes progressively smaller, but at the same time seed yields also decrease, due to the fact that the plants have a shorter period for development. If mechanical seed harvesting is to be used in the future, planting can be done anytime during the months of July and August, depending upon the requirements of the machine and the nature of the plant material with which it will work to best advantage.

The results of this investigation show that much larger yields of seed can be produced by planting in continuous rows 20 inches apart

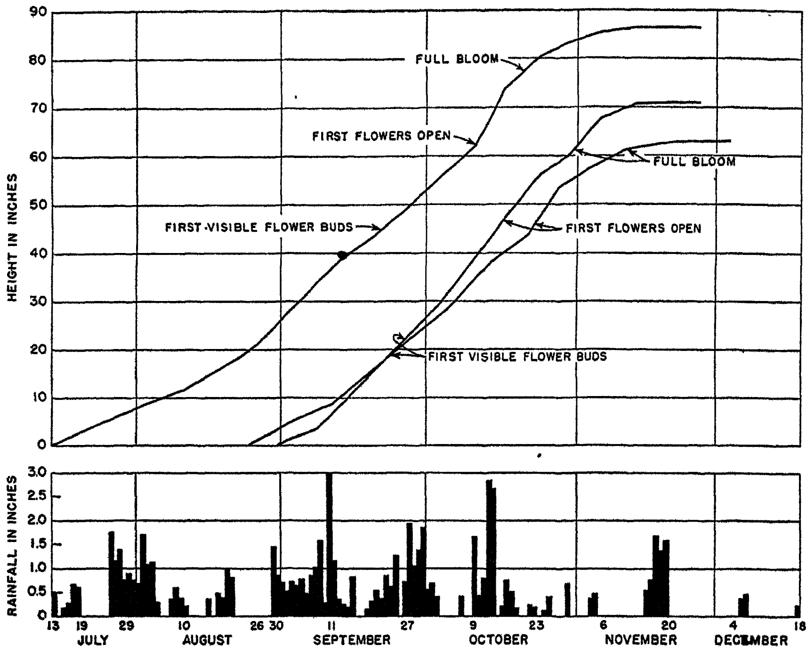

FIG. 1.—Growth and morphological development of kenaf planted on three different dates, with growth records starting from time of germination which was about 3 days after planting.

than by planting in hills at various distances. This planting method is readily adaptable to mechanization as 12-row grain drills with 8 inches between drills are already being used in Cuba in sowing kenaf for fiber production. In using these machines in planting for seed production, four rows, 24 inches apart, can be planted at a time by closing off the remaining drills.

Knowing the photoperiodic response of this plant to varying periods of daylight, a recommendation can be made as to the best time to plant for fiber as well as for seed production. In the production of any bast fiber, it is highly desirable to have long clean stems free of branches or fruiting stalks which interrupt the continuity of the fiber. Planting, therefore, must be done at the time of year when the days are of 12½ hours duration or longer and remain that way over a period of 3 or 4 months. This is necessary in order to prevent flower bud initiation until after the plants reach a sufficient height to insure adequate yields of fiber per area of land. As Cuba is located within the limits of 20° to 23° North Latitude, the days with 12½-hour day lengths or longer comprise the months of April through August. Fortunately, this period also includes the major portion of the rainy season. Planting for fiber as late as the middle of July to the last of August, however, does not give the plants sufficient time to grow vegetatively before flowering begins, and the crop does not reach ample height to produce adequate yields of fiber. Planting as early as

the first of April in some years would not be possible in Cuba due to the fact that the rains might not begin until sometime in May. Therefore, plantings for fiber may be made from the beginning of the rainy season (April or May, depending upon local conditions) until the middle of July. Larger yields of fiber will be obtained from plantings made during the early part of this period than from plantings made later.

SUMMARY

In order to determine the effect of time and distance of planting on seed yield of kenaf, observations were made at the Cuban Agricultural Experiment Station on plants which were planted on three separate dates and at five different planting distances. Data which were collected periodically throughout the life cycles of the plants with respect to growth, morphological development, seed yield, and environmental conditions are presented in tables and a graph.

Plant response to time and distance of planting, as measured by growth and seed production, is discussed in relation to changes in length of the daily light period.

The following conclusions have been drawn:

1. Time and distance of planting under the conditions of this investigation had little influence on the degree of branching in either *viridis* or *vulgaris*.
2. Regardless of time of planting during the rainy season, flowering of kenaf will not take place at 23° North Latitude until September or October when the length of the daily light period is shortened to approximately 12½ hours.
3. Plantings for seed should be made during the months of July or August, but under the conditions of this experiment higher yields of seed per plant were obtained from plantings made in July.
4. For high yields of seed per unit of land, planting should be done by drilling in rows 20 to 24 inches apart with 2 or 3 inches between plants in the row.
5. Planting for fiber can be done from the beginning of the rainy season (April or May, depending upon local conditions) until the middle of July, but it is preferable to plant as early during this period as possible.

LITERATURE CITED

1. ACUNA, JULIÁN, CLOVER, H. F., and GUERRERO, FERNANDO. Report on observations on roselle cultivation in El Salvador made by Dr. Julián Acuña and the Commission sent by the Cuban Government. 1942. (Processed) Copy in the Office of Foreign Agricultural Relations.
2. CHOUSSY, FELIX. Plan for the cultivation and exploitation of roselle in El Salvador. 1943. (Processed) Copy in the Office of Foreign Agricultural Relations.
3. DEKKER, J. F. Java-jute en roselle. Landbouw., 9: 507–513. 1934.
4. HOWARD, ALBERT, and HOWARD, G. L. C. Studies in Indian fibre plants: II. On some new varieties of *Hibiscus cannabinus* L. and *Hibiscus sabdariffa* L. India Dept. Agr. Mem., Bot. Ser., 4: No. 2. 1911
5. OLIVEIRA, ARISTIDES CARVALHO DE. Papoula de Sao Francisco (*Hibiscus cannabinus* L.) Bol. de Min. da Agr., 31, 7: 1–10. 1942.
6. WASSERMAN, JOSEPH. Recent investigations on the new bast fibers in U. S. S. R. Rayon and Melliand Textile Monthly, 16: 146–148. 1935.

SUCCESSIONAL TRENDS ON A CONSERVATIVELY GRAZED DESERT GRASSLAND RANGE[1]

HORACE S. HASKELL[2]

RETROGRESSIVE succession from a grassland to a desert shrub type on portions of the semi-desert grassland area in southern Arizona has been effected by heavy utilization by range livestock. Presumably, under the pressure of continued heavy stocking, the more palatable grasses have been depleted in vigor, density, and reproductive capacity. As a result, reduced competition of the more palatable grasses has permitted an increase in the less desirable grasses and shrubs, coincident with the decline in density of the former climax species. Discontinuous stands of perennial grasses dominated by mesquite, burroweed, and snakeweed attest the former occurrence of a desert grassland type, originally free of high concentration of shrubs and unpalatable grasses.

The retrogressive trend is arrested if conservative grazing, with soil and moisture conservation practices, is initiated. This trend is illustrated in the portion of the Page-Trowbridge Experimental Ranch (Fig. 1) which has been under intensive land management since 1923. The present study reports results obtained by use of the line interception method, showing the differences in vegetational composition and density between an area under conservative management and a comparable area of adjacent overgrazed range. Succession trends on the conserved range were inferred from studies of localized denuded areas and from a study of variation in composition with total grass density.

THE STUDY AREA

The areas considered in this study are located 8 miles west of Oracle, in southern Pinal County, Arizona, at an elevation of 3,700 feet. The portion used to study the effects of conservative grazing was the former Page Ranch, now a portion of the Page-Trowbridge Experimental Ranch; the overgrazed range used for comparison adjoins the eastern fence line of the Ranch. Each portion comprises 320 acres.

CLIMATE

Climatic conditions of the Page-Trowbridge Experimental Ranch are typical of moderate elevations throughout southern Arizona. Precipitation is almost entirely in the form of rain and falls during two distinct periods, a warm summer period from July through September and a mild winter-spring period from December through March. The intervening months are characteristically dry with low relative humidities. Monthly precipitation and temperature data, based on a

[1]Contribution from Department of Botany and Range Ecology, University of Arizona, Tucson, Ariz. Received for publication May 19, 1945.

[2]Research Assistant. The writer is indebted to Dr. R. A. Darrow, Associate Range Ecologist, University of Arizona, for his advice and criticism given throughout this study. To others who aided in this study, grateful acknowledgment is given, especially to K. W. Parker and R. H. Canfield of the Southwestern Forest and Range Experiment Station for use of equipment necessary for the survey and also for suggestions as to procedure; to Darwin Anderson of the Division of Conservation Experiment Stations, Soil Conservation Service, and E. L. Beutner, formerly of the Soil Conservation Service, for the photographs, aid in field work, and criticism of the investigation.

36-year record, are given in Table 1 for the nearest station, Oracle, at an elevation 800 feet higher than the study area. Interpolation of the Oracle data with a short-period record taken by the Soil Conservation Service indicates a mean annual rainfall at the Page-Trowbridge Experimental Ranch of 15 to 16 inches.

SOILS AND EROSION

The soils on the study area are alluvial soils of granitic origin and belong to the Reddish-Brown group (1)[3]. Generally, their surface horizons are of reddish-brown friable loam or sandy loam, slightly acid in reaction. The subsoils consist of heavy red clay or clay loam with columnar structure which becomes gray and distinctly calcareous at a depth of 2 to 3 feet.

TABLE 1.—*Monthly precipitation and mean temperature for Oracle, Ariz.*

Month	Precipitation, inches	Temperature, °F
January	2.02	46.0°
February	1.80	48.2°
March	1.67	52.5°
April	.77	59.5°
May	.37	67.4°
June	.40	77.5°
July	3.01	79.6°
August	3.23	77.4°
September	1.39	73.3°
October	.94	63.6°
November	1.57	54.9°
December	2.25	46.1°
Annual	19.42	62.2°

Soil erosion is more severe on the overused area than on the conserved portion. Three washes anastomose near the boundary separating the two areas, with the result that run-off water, heavily laden with eroded soil particles from the immediate drainage area, accumulates in the southeastern portion of the conserved area. As shown in Fig 1, active development of arroyos is evident on most of the washes in the area surrounding the conserved area in marked contrast to the heavily-vegetated drainages of the Page Ranch proper.

PROCEDURE

Data for density and frequency analyses of the vegetation of the conserved and overused areas were obtained by the line interception method (2, 3, 4). The sample unit consisted of a line 50 feet in length and the representative sampling method (3, page 8) was used to obviate the chance of concentrating all samples in one part of the area. Each 320-acre study area was subdivided into eight 40-acre blocks and 20 sample units randomized within each block. Randomization of sample units within blocks was obtained by the random selection of positions on two coordinate axes, the southern and western boundaries of each block. Sample units were laid out in a north-south direction at right angles to the prevailing slope.

Table 2 shows the vegetation intercepted expressed in mean feet of total grass, forb, and shrub cover for the eight 40-acre blocks of both the conserved and overused ranges. The plant population was segregated into two classes based on the method of measurement, *viz.*, (a) perennial grasses and herbs, measured at ground level; and (b) shrubs, measured on the crown spread as intercepted by the vertical projection of the line.

Reliability of means in sampling for each block was tested by calculation of the standard errors by Bessel's formula. Sampling accuracy was determined from

[3]Figures in parenthesis refer to "Literature Cited," p. 990.

TABLE 2.—*Mean feet ± standard error of grasses and forbs intercepted at ground level and crown spread of shrubs on 40-acre blocks of the conserved and overused ranges, block means based on 20 50-foot lines, measurements are to nearest 0.01 foot.*

	Conserved range								
	Block 1	Block 2	Block 3	Block 4	Block 5	Block 6	Block 7	Block 8	Average
Grasses	0.98±0.20	0.74±0.07	0.74±0.12	0.75±0.27	0.42±0.07	0.71±0.12	0.95±0.17	0.83±0.21	0.76±0.06
Per. herbs	0.10±0.06	0.05±0.02	0.22*	0.01*	0.05±0.03	0.04±0.01	0.30±0.23	0.33±0.25	0.14±0.04
Shrubs	1.41±0.51	2.25±0.52	2.03±0.31	2.99±0.48	3.14±1.05	1.27±0.67	1.66±0.78	0.45±0.23	1.90±0.31
	Overused range								
	Block 9	Block 10	Block 11	Block 12	Block 13	Block 14	Block 15	Block 16	Average
Grasses	0.10±0.06	0.01*	0.02±0.01	0.01*	0.02*	0.10*	0.08±0.02	0.10±0.02	0.06±0.01
Per herbs	0.02*	0.03*	0.02*	0.01*	0.02*	0.04*	0.01*	0.03*	0.02±0.01
Shrubs	5.36±0.74	4.50±0.71	3.46±0.50	3.70±0.71	2.64±0.64	2.67±0.39	6.07±0.68	5.64±0.69	4.26±0.47

*Occurred on 5 or less lines.

the standard errors of the total grass cover and a sample was considered sufficiently accurate if the mean exceeded its standard error in Table 2 by 3 or more times. Examination of the data will reveal that this was true in most cases. The accuracy of sampling the shrub cover was tested in a similar manner.

Table 3 shows the vegetational analysis in terms of density, per cent composition, and percentage species frequency. Density measurements are the computed percentages of the mean ground surface actually occupied by the herbaceous plants and the per cent ground covered by the crown spread of the shrubs as intercepted on the line. Composition is the percentage of ground cover contributed by each species. Frequency is the percentage of sample units in which a species occurs.

VEGETATIONAL ANALYSIS

Results of the vegetational analysis of the conserved and overused areas during the spring of 1941 are shown in Table 3. Density, composition based upon density, and frequency are segregated as to species and growth forms.

CONSERVED RANGE

The conserved area supports a grassland-desert shrub community. The grass dominants consist of poverty three-awn (*Aristida hamulosa* Henr.), red three-awn (*A. longiseta* Steud.), and Rothrock grama (*Bouteloua rothrockii* Vasey) which make up nearly 60% of the total herbaceous cover.

In swales and drainage bottoms cane beardgrass (*Andropogon barbinodis* Lag.) and Johnson grass (*Sorghum halepense* (L.) Pers.) replaces the general dominants and forms dense stands of closely-spaced clumps. On the upland areas, grasses of secondary abundance

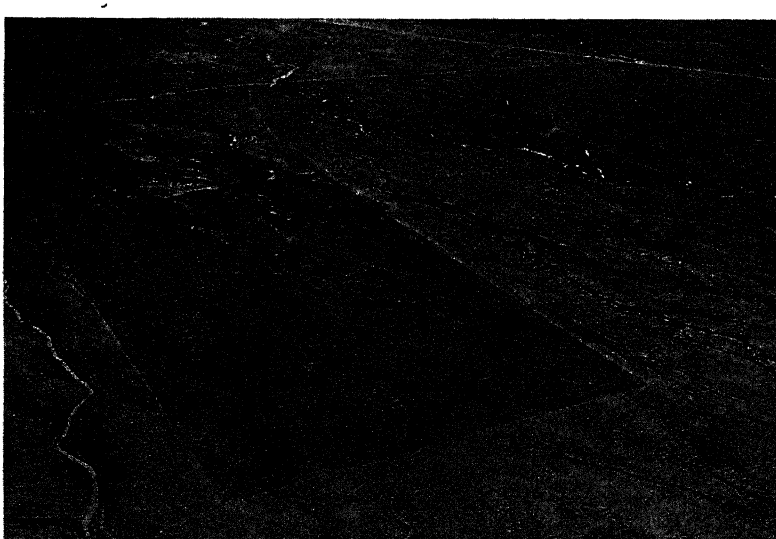

FIG. 1.—Aerial view of the study area taken from the northwest. The darker area is the conserved area, this aspect being due to the heavier stand of perennial grass.

TABLE 3.—*Density, composition, and frequency of grasses, perennial herbs, and trees and shrubs on conserved and overused areas.*

Species	Conserved area			Overused area		
	Density, %	Composition, %	Frequency, %	Density, %	Composition, %	Frequency, %
			Grasses			
Red three-awn	0.65	36.1	85.3	*	*	3.7
Rothrock grama	0.30	16.8	75.6	0.06	37.7	39.4
Cane beardgrass	0.18	10.0	24.4	0.02	12.5	1.9
Poverty three-awn	0.15	8.4	21.9	*	*	1.2
Side-oats grama	0.12	6.7	10.6	—	—	—
Black grama	0.04	2.2	3.7	—	—	—
Curly mesquite	0.04	2.2	5.6	0.01	6.2	1.2
Hairy grama	0.02	1.1	0.6	—	—	—
Johnson grass	0.01	0.5	1.2	—	—	—
Fluffgrass	0.01	0.5	2.5	0.02	12.5	4.3
Plains bristlegrass	—	—	—	0.01	6.2	0.6
Plains lovegrass	*	*	0.6	—	—	—
			Perennial Herbs			
Fleabane	0.20	11.1	8.7	*	*	1.9
Gaura	0.05	2.8	24.4	*	*	0.6
Stephanomeria	0.02	1.1	3.1	*	*	2.5
Thistle	0.01	0.5	0.6	—	—	—
Ragweed	*	*	0.6	—	—	—
Desert-holly	*	*	0.6	—	—	—
Larkspur	*	*	0.6	—	—	—
Desmanthus	—	—	—	0.01	6.2	1.9
Senna	—	—	—	0.02	12.5	10.6
Pipe vine	—	—	—	0.01	6.2	0.6
Gourd	—	—	—	*	*	1.2
Boerhaavia	—	—	—	*	*	0.6
Total	1.80	100.0		0.16	100.0	
			Trees and Shrubs			
Burroweed	1.98	52.0	59.3	6.38	75.0	98.0
Snakeweed	—	—	—	0.84	9.9	45.0
Mesquite	0.66	17.4	13.1	0.76	9.0	16.2
Wright buckwheat-brush	0.64	17.0	25.0	0.02	0.1	1.2
Desert broom	0.32	8.3	1.9	—	—	—
Wait-a-minute	—	—	—	0.18	2.1	1.9
Prickly pear	0.04	1.1	3.1	0.15	1.8	10.0
Soaptree yucca	0.05	1.4	1.9	0.10	1.0	1.9
Cholla	0.07	1.9	7.5	0.08	0.9	7.5
Bisnaga	0.03	0.7	1.2	0.01	0.2	0.6
Fishhook cactus	0.01	0.2	0.6	—	—	—
Catclaw	*	*	0.6	*	*	0.6
Desert-thorn	—	—	—	*	*	0.6
Total	3.80	100.0		8.52	100.0	

*Trace.

are side-oats grama (*Bouteloua curtipendula* (Michx.) Torr.), black grama (*B. eriopoda* Torr.), hairy grama (*B. hirsuta* Lag.), and curly mesquite (*Hilaria belangeri* (Steud.) Nash). Plains lovegrass (*Eragrostis intermedia* Hitchc.) occurred frequently in the sample units, but since the plants were small in size, the density is recorded as only a trace.

A few small patches of sand dropseed (*Sporobolus cryptandrus* (Torr.) A. Gray), bush muhly (*Muhlenbergia porteri* Scribn.), and Arizona cotton grass (*Trichachne californica* (Benth.) Chase) were observed, but did not occur within the sample units.

Forbs add little to the sum of the vegetation except during the spring and summer rainy seasons. The perennial herbs were represented chiefly by gaura (*Gaura coccinea* Nutt.) and fleabane (*Erigeron* spp.). As shown in Table 3, gaura has an intermediate percentage composition but a high frequency, due to a large number of small plants per line. Fleabane is a larger plant, hence, there are fewer plants per line but the density is higher than for gaura. Forbs of secondary importance include thistle (*Cirsium* sp.), stephanomeria (*Stephanomeria pauciflora* (Torr.) A. Nels.), larkspur (*Delphinium scaposum* Greene), ragweed (*Franseria confertiflora* (DC.) Rydb.), and desert holly (*Perezia nana* A. Gray).

Due to the extremely favorable winter precipitation, a heavy cover of spring annuals was present, at the time of the study. Alfileria (*Erodium cicutarium* (L.) L'Her. ex Ait.), a rosette-forming annual, occurred abundantly. Other annuals such as Indian wheat (*Plantago fastigiata* Morris), goldfields (*Baeria chrysostoma* Fisch. et Mey. var. *gracilis* (DC.) Hall), owls clover (*Orthocarpus purpurascens* Benth.), etc., also occupied much of the open ground between the grass clumps.

The principal small shrubs, burroweed (*Aplopappus tenuisectus* (Greene) Blake) and Wright buckwheatbrush (*Eriogonum wrightii* Torr. ex. Benth.), are similar in height to the dominant grasses. As shown in Table 3 these shrubs form 70% of the shrubby cover. Ranking next in dominance is mesquite, (*Prosopis juliflora* (Swartz) DC. var. *velutina* (Woot.) Sarg.), a small tree which gives a savanna aspect. Other desert shrubs of lesser importance include cholla (*Opuntia spinosior* (Engelm. and Bigel.) Toumey and *O. fulgida* Engelm.), prickly pear (*O. engelmanii* Salm-Dyck ex Engelm.), soaptree yucca (*Yucca elata* Engelm.), desert broom (*Baccharis sarothroides* A. Gray), bisnaga (*Echinocactus wislizenii* Engelm.), and fishhook cactus (*Mamillaria* spp.). Catclaw (*Acacia greggii* A. Gray) occurred on a few sample units (Table 3), but was not a prominent component of the shrubby element.

OVERUSED RANGE

The small, discrete shrubs of the overused area are interspersed with scattered large shrubs, small trees, annual weeds, and grass clumps. Rothrock grama is the principal grass species, its density being only 0.06% but its frequency is 39.4% (Table 3). Cane beardgrass forms a meager cover in drainage bottoms and swales, while

fluffgrass (*Triodia pulchella* H. B. K.) assumes importance on eroded upland soils. Grasses of secondary abundance are plains bristlegrass (*Setaria macrostachya* H. B. K.) and curly mesquite.

The principal forbs on the overused area are senna (*Cassia bauhinioides* A. Gray), fleabane, desmanthus (*Desmanthus cooleyi* (Eaton) Trel.), gourd (*Cucurbita digitata* A. Gray), and stephanomeria. As shown in Table 3, the weeds of secondary importance including pipe vine (*Aristolochia watsoni* Woot. and Standl.), boerhaavia (*Boerhaavia* spp.), and gaura, vary in frequency and composition depending upon their size and abundance.

Annuals were abundant, as on the conserved range, the principal species being alfileria, Indian wheat, goldfields, etc.

Dominant shrubs were burroweed, 6.38% density, and snakeweed (*Gutierrezia lucida* Greene), 0.84% density, with prickly pear, cholla, and mesquite as important secondary species. Minor shrubs include wait-a-minute (*Mimosa biuncifera* Benth.), soaptree yucca, desert thorn (*Lycium berlandieri* Dunal in DC. var. *parviflorum* (Gray) Terrac.), and catclaw.

DISCUSSION

The differences in vegetation on the two areas as measured in this study are due principally to conservative stocking and range improvement practices on the conserved range as contrasted to unregulated grazing on the overused area. On the conserved range, natural establishment of grasses was encouraged by the removal of unpalatable shrubs by hand-grubbing. The development of water-retaining structures such as check dams, dikes, and contour furrows on locally-denuded areas aided in the transformation from the xeric conditions, favoring desert-shrub development, to the more favorable moisture conditions of a well-managed grassland.

Detailed information is lacking concerning the character of the vegetation of the study areas at the time Mr. Page established his ranch in 1923. However, it may be assumed that unregulated grazing of public lands, characteristic in southern Arizona since the late 1870's, had already caused a marked deterioration in the range vegetation by 1923. Since 1923, the vegetation adjacent to the ranch has continued to retrogress under sustained heavy use by livestock. As shown in Fig. 2 the conservative grazing of three to five head of cattle yearlong by Mr. Page on his 320 acres has resulted in the re-establishment of a perennial grass cover approaching the climax.

COMPARISON OF VEGETATION ON THE CONSERVED AND OVERUSED RANGES

The Page Ranch, or conserved area, shows a greater density and higher quality of perennial grasses than the overused area. On the conserved range, perennial three-awns (principally red and poverty three-awn) comprise 44.5% of the composition, whereas on the overused range these occur as trace. Rothrock grama constituted 37.7% of the composition on the overused area, but in actual density, this species is much more important on the Page Ranch. Other

grasses, such as black grama, curly mesquite, slender grama, side-oats grama, etc., that form an integral part of the climax perennial cover at higher elevations in the desert grassland belt, occur on the conserved area in limited amounts and are entirely absent on the overused area. Fluffgrass, a nonpalatable species, makes up 12.5% of the composition on the overused area but only 0.5% on the conservatively managed tract.

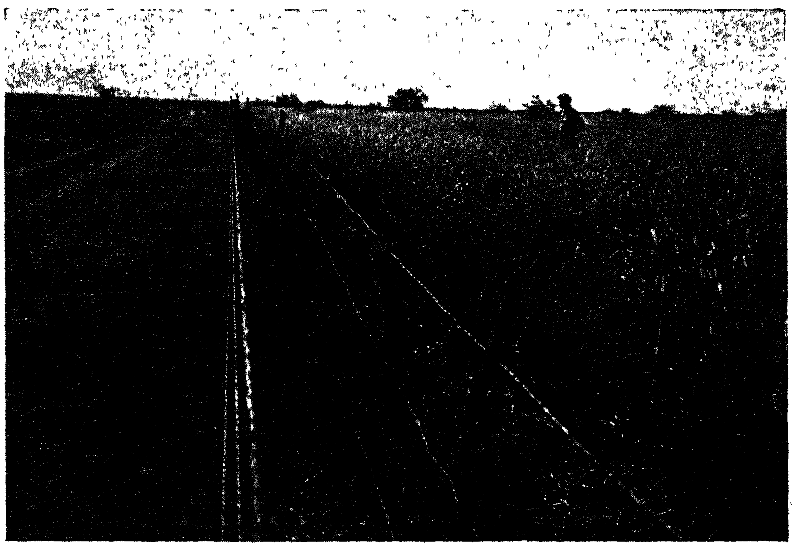

FIG. 2.—Fence line contrast on the study area. The conserved range (Page Ranch) is on the right, the overgrazed range on the left. The vegetation shown in the photograph on the conserved range is primarily cane beardgrass and mesquite; whereas on the overused area it is chiefly burroweed, annuals, and mesquite.

Table 3 shows a significant difference between the density of burroweed on the conserved and overused areas. On the Page Ranch, in the southern and eastern portion of the range, burroweed was almost eradicated by grubbing, whereas in the northern and western portions, little or no grubbing was practiced. The density of burroweed in this latter portion of the Page Ranch is similar to that on the overgrazed area. Once burroweed becomes established, its longevity and aggressive seeding habits make the species a conspicuous component of the vegetation even under complete protection from grazing for periods of more than 20 years. To effect any considerable reduction in the stand, as shown on the conserved range, eradication by mechanical measures is necessary.

The other small shrubs, snakeweed and Wright buckwheat-brush, show an inverse relationship on the two areas. Snakeweed is lacking on the conserved area but comprises 9.9% of the shrubby cover on the overused range, whereas Wright buckwheatbrush constitutes 0.1% of the composition on the overused area as con-

trasted to 17.0% on the conserved range. Snakeweed is similar in habit, growth form, and palatibility to burroweed, but is less aggressive and shorter lived. After several years of light or nonuse on a range where snakeweed was formerly abundant, the stands of this plant have materially diminished. On the other hand, Wright buckwheatbrush is a palatable shrub and maintains itself under moderate grazing. Snakeweed and Wright buckwheatbrush were likewise subjected to control measures on the Page Ranch, hence the direct influence of conservative grazing as it affects the latter two shrubby components is not determinable.

SUCCESSIONAL TRENDS ON THE CONSERVED RANGE

The conserved range is at present in a subclimax stage, and is developing toward the climax. The subclimax character of the area is demonstrated by the persistent populations of burroweed, particularly in the portions of the ranch not influenced by plant control measures. Black grama and sub-climax species such as slender grama and perennial three-awns are represented by isolated low density stands that have not assumed the degree of dominance attainable under climax conditions.

Species composition and density of sample units containing climax and near-climax species is shown in Table 4 in comparison to the average density and composition for the entire area. As the latter data indicate the general subclimax character of the vegetation as a whole, inspection of localized areas characterized by climax and near-climax species may indicate possible composition and density trends at or approaching climax status. For example, black and slender grama grasses are definite climax constituents of desert grassland at comparable elevations in southern Arizona. As shown in Table 4, the sample units containing these species have a composition and density of associated grasses similar to that of the average vegetation. The average density of slender and black grama on all sample units is 0.04%, whereas if the lines containing these two species are considered as a separate unit, the density is 1.08%. The densities of burroweed and Wright buckwheatbrush are similar to that of the average density, but low density of minor shrub species creates a low total shrub density on the sample units containing these climax gramas.

Perennial three-awns comprise 45.3% of the perennial grass cover on the conserved area and represent climax components of the desert grassland type. If sample units with a high proportion of perennial three-awns are analyzed, grass densities higher than average and shrub densities lower than the general average are obtained. Associated grasses present in such a selected sample do not vary widely in composition, however, from that of the general average. The total grass density is higher due to the threshold value of 2.00% used for perennial three-awns.

Cane beardgrass is a postclimax species and attains dominance in swales and water-retaining areas. The total grass densities of

TABLE 4.—*Density and composition of grasses and shrubs on sample units containing climax and near-climax species on the conserved range.*

Species	Sample unit containing: Slender and black grama (7)*		Perennial three-awns (17)†		Cane beard grass (39)		Wright buckwheatbrush (40)		Total lines (160)	
	Density %	Composition %	Density %	Composition %	Density %	Composition %	Density %	Composition %	Density %	Composition %
GRASSES										
Perennial three-awn	0.82	32.5	3.12	79.4	0.88	37.2	0.58	44.0	0.80	52.6
Rothrock grama	0.34	13.4	0.30	7.5	0.18	7.6	0.50	38.0	0.30	19.9
Cane beard grass	0.10	4.0	0.32	8.1	0.74	31.2	0.12	9.0	0.18	11.9
Slender & black grama	1.08	43.0	0.06	1.5	0.04	1.7	0.08	6.0	0.04	2.7
Side-oats grama	0.14	5.5	0.10	2.0	0.38	16.1	0.02	1.5	0.14	9.3
Minor species	0.04	1.6	0.06	1.5	0.14	6.2	0.02	1.5	0.06	3.6
Total	2.52	100.0	3.96	100.0	2.36	100.0	1.32	100.0	1.52	100.0
SHRUBS										
Burroweed	1.98	80.0	0.74	58.6	0.92	64.0	3.26	53.0	1.98	52.0
Wright buckwheatbrush	0.46	18.4	0.20	15.9	0.25	17.3	2.56	40.0	0.64	17.0
Minor species	0.04	1.6	0.32	25.5	0.27	18.7	0.46	7.0	1.18	31.0
Total	2.48	100.0	1.26	100.0	1.44	100.0	6.28	100.0	3.80	100.0

*Figure in parenthesis refers to number of sample units in which the grass or shrub occurred.
†On lines exceeding density of 2.0% of perennial three-awns, principally red and poverty three-awn.

sample areas with this species exceeds that of the average type; shrub density is correspondingly lower. Associated grass species exhibiting marked divergence from the average are Rothrock grama with reduced density and side-oats grama with a higher density. The latter species is climax in the higher altitudes of the desert grassland type and occupies a postclimax role under the more xeric conditions of the conserved area.

The subclimax nature of the conserved area is not as distinctly shown by the shrubby components as by the grasses. Wright buckwheatbrush is a subclimax species as evidenced by Table 4 which shows a high density of subclimax vegetation such as Rothrock grama and burroweed on sample units containing Wright buckwheatbrush and a correlated low total grass density. The general absence of snakeweed confirms other evidence that vegetational development is toward the climax, for it is a short-lived perennial shrub, and under conservative management is one of the first shrubby species to disappear. Burroweed, as previously indicated, is markedly reduced only by artificial control, hence cannot be used as a natural indicator of early progressive successional trends.

Further evidence of the stages in secondary succession may be derived from the relationship between total grass density and individual species density, as shown in Fig. 3. As heretofore assumed, secondary succession results in an increase in perennial grass density, the site remaining the same. Therefore, localized areas of low total density represent lower stages in succession than areas of higher vegetational density. Changes in the relative densities and composition of the species on sample units with an increase in total grass density as shown in Fig. 3 may be considered broadly indicative of the general successional changes taking place on the area as a whole.

On the basis of individual species densities (Fig. 3, A), as well as per cent composition (Fig. 3, B), the present trend is toward an herbaceous cover composed of perennial three-awns and the more palatable grama grasses on the Page Ranch. On areas with higher densities than the present average conditions, density of the perennial three-awns and climax gramas tends to increase with an increase in herbaceous density. Rothrock grama shows an irregular, but negative trend and for cane beardgrass the trend is uniform. This uniformity of the cane beardgrass is partially due to the sampling, for several large areas dominated by this grass were not included in the data.

Consideration of these changes in composition with increasing density may be observed on localized denuded areas on the conserved range. Under favorable moisture conditions these denuded areas become covered with an annual vegetation which is invaded by the short-lived perennial Rothrock grama. This species is in turn partially replaced by the perennial three-awns which may ultimately form a mixture with other climax grasses.

SUMMARY AND CONCLUSIONS

The effects of conservative grazing on a deteriorated desert grassland range (the Page-Trowbridge Experimental Ranch and adjoining

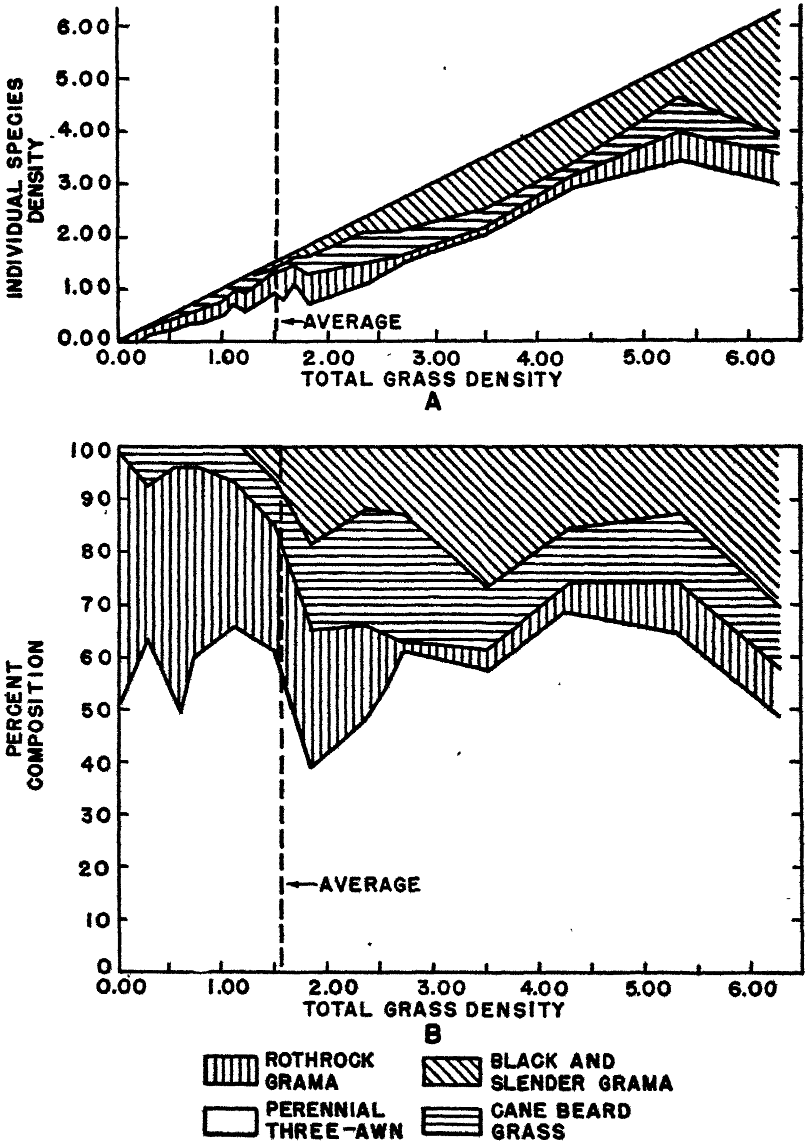

FIG. 3.—Total densities of grass and individual species on the conserved area. A, based on individual species densities; B, based on percentage composition.

area) in southern Arizona was studied by means of the line interception method. The portion of the Page-Trowbridge Experimental Ranch which has been under conservative use since 1923 was compared with the severely-grazed area adjoining the eastern boundary of the Ranch.

The results show that by instigating range conservation on an area undergoing retrogressive succession, the trend is reversed and development toward climax conditions is initiated. In the desert grassland area of southern Arizona, heavy grazing develops a desert shrub-grassland community in which burroweed is dominant and perennial grasses are widely scattered. Conservative grazing leads to the development of a grassland-desert shrub community in which the perennial three-awns, Rothrock grama, and burroweed become dominant in the subclimax condition.

The climax perennial grasses that normally form an integral part of the cover at higher elevations, occur on the conserved area in limited amounts and are entirely absent on the overused area. Shrubby plants are more conspicuous on the overgrazed range, their presence on the conserved area being masked by the herbaceous vegetation.

The results indicate that the conserved range, at present, is in a subclimax stage, undergoing progressive succession toward the climax stage. The following conditions are evidence of secondary succession following retrogression caused by intensive grazing:

1. Slight changes in the long-lived, more aggressive invaders. Certain portions of the study area appear to be so completely dominated by burroweed that it seems doubtful if the climax plants can ever gain a foothold, unless artificial means of control are employed.

2. Disappearance of the short-lived, perennial, worthless plants such as snakeweed and weeds.

3. Increase in the more palatable, perennial grasses. Rothrock grama, a pioneer species, becomes established first, and eventually the site becomes favorable for the establishment of perennial three-awns and ultimately the grama grasses and other climax species.

LITERATURE CITED

1. ANONYMOUS. Soils of the United States. U. S. D. A. Yearbook, 1938: 1019–1161. 1938.
2. CANFIELD, R. H. Application of the line interception method in sampling range vegetation. Jour. Forestry, 39: 388–394. 1941.
3. ———. Sampling ranges by the line interception method. Southwestern Forest and Range Exp. Sta. Rpt., 4. 1942.
4. ———. Measurement of grazing use by the line interception method. Jour. Forestry, 42: 192–194. 1944.

THE BEHAVIOR OF THE SELF-COMPATIBILITY FACTOR AND ITS RELATION TO BREEDING METHODS IN *TRIFOLIUM REPENS*[1]

SANFORD S. ATWOOD[2]

WITH most self-incompatible plants, controlled crossing on a large scale can be easily accomplished by growing the selected individuals in isolation, but with self-compatible plants the problem of outcrossing is more complex. In the case of white clover, *Trifolium repens*, a self-compatible plant was observed to produce only 19% outcrossed progeny following "natural crossing" by bees (4),[3] and it was concluded that the amount of crossing obtained under field conditions with clones of this type probably would not be adequate for most practical breeding purposes. Instead it would seem to be necessary with self-compatible lines to eliminate the S_f gene by controlled matings before attempting to combine them on an extensive scale.

From genetic studies (2) of this character, however, it was concluded that the gene may be very useful in facilitating inbreeding. It was also recognized that the ultimate method of its utilization would depend on several behavior factors, none of which was completely understood. Recently, some of these factors have been studied more in detail, and since no further work along this line is contemplated for the present, the principal results are summarized here.

MATERIALS AND METHODS

All self-compatible plants used in these studies were derived from the original cross which was used to investigate the inheritance of the S_f gene (2). The unrelated, self-incompatible plants used in certain crosses were selected from open-pollinated seed lots which had been grown from a number of different sources in order to make first selections based on several important agronomic characters.

The methods used for testing self- and cross-compatibility in both greenhouse and field were the same as those used earlier (1, 2).

EXPERIMENTAL RESULTS

The studies were made in an attempt to answer several specific questions, and the results presented accordingly.

[1]Contribution No. 74 of the U. S. Regional Pasture Research Laboratory, Division of Forage Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture, State College, Pa., in cooperation with the northeastern states. All data were collected and most of the summaries were made while the writer was at the Laboratory; final analyses were made and writing of most of the manuscript was completed at Cornell University. Abstract published in this Journal, Vol. 36, page 990. 1944. Received for publication May 26, 1945.

[2]Formerly Associate Agronomist; now Associate Professor of Plant Breeding, Cornell University, Ithaca, N. Y.

[3]Figures in parenthesis refer to "Literature Cited", p. 1004.

IN A HETEROZYGOUS S_fS_x PLANT, ARE THE TWO TYPES OF GAMETES PRODUCED IN EQUAL NUMBERS AND DO THEY FUNCTION EQUALLY WELL?

This question was raised when the original F_1 and F_2 populations showed a deficiency of self-compatible segregates. In both cases the S_f gene had been introduced into the progenies from the male parents of the crosses. It appeared that S_f pollen was not as effective as S_8 pollen when the two were applied together on a stigma which bore two other alleles. Since these original populations were relatively small, additional plants were grown and self-pollinated in the field, generally using eight heads per plant. When it was noticed that the distribution of plants within families was not distinctly bimodal (Table 1), those plants that were considered to be in the overlapping range (15 to 60 seeds per head) and a few plants at random from the extremes of the distribution were brought into the greenhouse for more precise testing. The separation into self-compatible and self-incompatible plants for each family shown in Table 1 is based on the results of selfing and of crossing reciprocally with S_3S_8 and S_4S_8 tester plants in the greenhouse. In only 1 case out of the 15 plants sampled from both ends of the distributions did the greenhouse test result in a different classification from that given on the basis of field results. Of the 89 plants within the 15 to 60 range in average seed set, 80 plants were classified definitely according to greenhouse results. The remaining 9 plants did not flower in the greenhouse, but most of them were near the extremities of this range so there was somewhat less chance of their being wrongly classified. It is obvious from the distributions shown in Table 1 that field results were not reliable for classifying any except the best and the poorest seed setting plants. An average of 32 seeds is the demarcation line between self-incompatible and self-compatible plants that gives the fewest cases of overlapping (18 plants), but with this cross the two types could be distinguished with certainty only after controlled pollinations in the greenhouse.

The competitive ability of S_f pollen was tested by comparing the results from two types of crosses, *viz.* (a) using abundant pollen (family 1, Table 1), and (b) using a scant amount of pollen (family 2, Table 1). In order to test the proportion of S_f eggs that would function in a heterozygous S_f plant, a third cross was made using the self-compatible plant as female (family 3, Table 1). In each of the first two families there was a deficiency of self-compatible plants resulting in the ratio S. I./S. C., differing significantly from the expected ratio of 1/1 according to the X^2 test (corrected for continuity). On the other hand, the cross using the self-compatible plant as female gave rise to a family in which the segregation did not differ significantly from the expected 1/1 ratio. It is concluded that S_8 and S_f gametes were produced in approximately equal numbers by the S_8S_f plant at least following macrosporogenesis, but when pollen from this plant was placed on a stigma bearing two other alleles, the S_f pollen did not compete equally well with that bearing S_8.

TABLE 1.—*Frequency distribution, average seed set in field, total segregation, and corrected X^2 for the progeny from three crosses involving a heterozygous S_f plant and a self-incompatible plant bearing two other alleles.*

Family No.	Origin of families	Type of segregates*	Percentage of plants in the following classes of average seeds per head											Average seeds per head for all plants	Total number of plants		Corrected X^2
			0–10	10–20	20–30	30–40	40–50	50–60	60–70	70–80	80–90	90–100	100+		Obt.	Exp.	
1	$S_3S_4 \times S_8S_f$ (abundant pollen)	S.I.	48	28	10	10	2	—	2	—	—	—	—	15.0	50	32	19.141**
		S.C.	—	—	—	14	29	—	7	14	14	7	14	68.8	14	32	
2	$S_3S_4 \times S_8S_f$ (scant pollen)	S.I.	41	36	15	6	2	—	—	—	—	—	—	14.1	81	54.5	24.807**
		S.C.	—	—	7	21	14	18	11	11	—	7	11	60.5	28	54.5	
3	$S_8S_f \times S_3S_4$	S.I.	42	50	4	4	—	—	—	—	—	—	—	12.0	24	21	0.595
		S.C.	—	11	11	17	22	6	11	17	—	6	—	49.1	18	21	
Total S. I.														14.1	155		
Total S. C.														59.0	60		

*S. I. = self-incompatible; S. C. = self-compatible.
**Highly significant.

WHEN AN S_fS_x PLANT IS CROSSED AS MALE WITH A SELF-INCOMPATIBLE PLANT BEARING S_x, DOES THE S_x POLLEN FUNCTION BECAUSE OF ITS ASSOCIATION WITH S_f?

The problem is whether S_f behaves like the other alleles in the series with a strictly oppositional effect independent of any associated alleles, or whether by its own exceptional behavior it influences the oppositional behavior of associated alleles.

Two types of crosses were used:

$$1.\quad S_xS_y \times S_xS_f \longrightarrow S_xS_f + S_yS_f \boxed{+ S_xS_x + S_xS_y}$$

$$2.\quad S_xS_x \times S_xS_f \longrightarrow S_xS_f \boxed{+ S_xS_x}$$

In each of these crosses, if only the S_f pollen functions, all progeny should be self-compatible, but if the S_x pollen overcomes the oppositional effect because of its association with S_f, then some self-incompatible segregates should be obtained (as shown by the genotypes enclosed in the boxes). The evidence from 17 F_2 and 110 I_1 plants (2) had indicated that the pollen bearing the same allele as that found in the pistil in a cross or self of this type did not function to produce self-incompatible segregates. In tests with larger populations (Table 2), the distributions of the plants were skewed more toward the lower end of the curves than those of the self-compatible plants shown in Table 1, and the average seed set was significantly lower. Part of this difference may have resulted from the reduced vigor exhibited by most of the plants listed in Table 2. Some of the plants grew so poorly that it was not possible at the end of their second summer in the field to isolate from them any viable cuttings which could be used for further testing in the greenhouse. In addition some of the plants that were obtained did not flower, but everyone of the questionable plants that was tested proved to be self-compatible. Altogether, 16 of the 30 plants shown in the 0 to 20 range in Table 2 as well as 17 at random from the 20 to 100 range were adequately tested, and all were shown to bear the S_f gene. It is concluded that S_x pollen maintains its strictly oppositional behavior despite its association with pollen bearing S_f.

Significant differences were noted (Table 8) between the average seed sets of the crosses listed in Table 2, and this behavior is attributed to the different modifying factors contributed by the different plants.

WHEN AN S_fS_x PLANT IS CROSSED AS A FEMALE WITH A SELF-INCOMPATIBLE PLANT BEARING S_x, DOES THE S_x POLLEN FUNCTION BECAUSE OF THE DOMINANT EFFECT OF S_f?

This question relates to the effect of the S_f gene in the pistil. When S_x pollen is placed on an S_fS_x pistil, does it function despite the oppositional influence of S_x? In preliminary tests (2), using

TABLE 2.—*Frequency distribution and average seed set for the progeny from four crosses involving a S_xS_y or S_xS_x female and a S_xS_f male.*

Family No.	Origin of families	Percentage of plants in the following classes of average seeds per head											Total number of plants	Average seeds per head for all plants
		0–10	10–20	20–30	30–40	40–50	50–60	60–70	70–80	80–90	90–100	100+		
4	$S_3S_8 \times S_3S_f$ (9–5)	6	12	28	22	16	6	3	3			3	*32	36.1
5	$S_3S_8 \times S_3S_f$ (9–9)	4	9	16	22	16	11	11	2	2	2	5	55	45.3
6	$S_4S_8 \times S_4S_f$	4	29	24	24	14	—	—	4	—	—	—	49	28.9
7	$S_3S_3 \times S_3S_f$	—	11	11	—	67	11	—	—	—	—	—	9	40.4
	Total	4	17	21	21	19	6	5	3	1	1	3	145	37.4

homozygous plants as males, the results indicated that S_f functioned as a partly dominant factor in the female parent permitting some seed set, but the number of crosses studied was too small to make any conclusion decisive. In order to test this hypothesis further, the crosses $S_xS_f \times S_xS_x$ and $S_xS_f \times S_yS_y$ were repeated in two years using a total of 74 heads on three different female plants (Table 3).

TABLE 3.—*Average seed set from the crosses $S_xS_f \times S_xS_x$ and $S_xS_f \times S_yS_y$.*

♀ plants	Year	Average seeds per 10 flowers from following crosses				
		♂ homozygous for same self-incompatible allele as in ♀		♂ homozygous for different self-incompatible allele than in ♀		Average
9–V	1st	5.7	5.8	25.9	32.4	19.2
(S_3S_f)	2nd	6.0		39.0		
9–VI	1st	17.0	14.5	26.6	32.0	23.3
(S_3S_f)	2nd	12.0		37.5		
9–VII	1st	25.0	20.0	45.9	43.6	31.8
(S_4S_f)	2nd	15.0		41.4		
Average		13.4		36.0		24.8

In every comparison the seed set from crossing with the male bearing different alleles was higher than that from crossing with the male bearing the same allele, and the average difference was highly significant (Table 4). On the other hand, the variances due to female plants, years, or interaction ♀ × ♂ were not significant. The fact that some seed was obtained using S_xS_x as male indicated that S_f functioned as a dominant factor, but the fact that the seed set was significantly lower when using S_xS_x than when using S_yS_y indicated that the dominance was not complete.

TABLE 4.—*Analysis of variance for seed set data shown in Table 3.*

Source	D.F.	Mean squares	F
♀	2	167.18	3.87
♂	1	1532.28	35.48**
Years	1	1.92	—
♀ × ♂	2	21.30	—
Error	5	43.19	
Total	11		

**Highly significant; exceeds F for P = .01.

An attempt was made to test the same proposition, using a heterozygous male:

$$S_xS_f \times S_xS_y \longrightarrow S_xS_y + S_yS_f \boxed{+ S_xS_x + S_xS_f}$$

If only the S_y pollen functions, all self-incompatible segregates will be heterozygous, whereas if the S_x pollen also functions, some homozygous S_xS_x plants will be obtained. With the progenies used here, the plants grew and flowered poorly, so that only 8 of the 12 self-incompatible plants were definitely identified. Since all of these proved to be heterozygous, however, it suggests that S_f did not function as a partly dominant allele in these crosses. The normal oppositional effect was not disturbed by the presence of S_f in the female in crosses where only part of the pollen was inhibited.

CAN HOMOZYGOUS S_fS_f PLANTS BE OBTAINED, AND HOW EFFECTIVE WILL THEY BE?

In order to utilize the S_f gene most effectively, it is desirable to have it in the homozygous condition so that when crosses are made to incorporate it into unrelated families, all resultant progeny will bear the factor and consequently be self-compatible. In the search for homozygous plants, 15 first-generation inbreds, all of which had come from the original self-compatible parent (9–11) and all of which had set large amounts of selfed seed in the field (2), were crossed as females in the greenhouse with a self-incompatible plant (9–1) which had been shown to have both S factors different from those of the inbreds' parent. The 285 plants (Table 5) in the 15 resultant families were then tested for self-compatibility by selfing in the field, and 72 of these plants were checked by controlled crosses and selfs in the greenhouse. Only one of the plants which was tested in the greenhouse proved to be a contaminant. The remaining four or five plants in each family gave expected results, with clear-cut segregations that confirmed the field results in every case. According to hypothesis, when a heterozygous self-compatible plant is self-pollinated, all progeny should be self-compatible, since only the S_f pollen should function (2), but half of the progeny should be heterozygous and half homozygous:

$$S_xS_f \times \longrightarrow S_xS_f + S_fS_f + \boxed{S_xS_x + S_xS_f}$$

In four of the 15 test families, no self-incompatible segregates were found (Table 5), indicating that their self-compatible inbred parents were homozygous S_fS_f, but segregation into both self-incompatible and self-compatible individuals was noted in the other 11 families, indicating that their self-compatible parents were heterozygous S_xS_f. This 4/11 segregation among the 15 tested I_1 plants does not differ significantly from the theoretical 1/1 ratio (corr. $X^2 = 2.400$). Likewise, with none of the segregating families nor with the total population (112/101) from these 11 families do the ratio S. I./S. C. differ significantly according to the X^2 test fr that expected on the 1/1 hypothesis.

TABLE 5.—*Number of plants, average seed set in field, and ranges in average and maximum seed set for 15 families used to test for S_fS_f parentage.*

Family No.	Origin of families	Total number of plants		Average seed set for all plants		Range in average seed set per head for individual plants		Range in maximum seed set per head for individual plants	
		S.I.	S.C.	S.I.	S.C.	S.I.	S.C.	S.I.	S.C.
8	9–67×9–1	0	22	—	50.4	—	22.0– 98.4	—	41–196
9	9–68×9–1	7	6	5.6	72.8	1.0–12.3	27.2–101.3	3–21	41.5–159
10	9–69×9–1	11	16	19.0	58.9	6.4–39.8	21.4– 75.4	9–57	63–139
11	9–70×9–1	0	19	—	63.8	—	19.6–104.8	—	37–172
12	9–71×9–1	12	10	21.8	61.9	6.7–35.3	468 – 93.0	19–69	76–128
13	9–72×9–1	9	8	15.1	71.1	5.0–34.0	47.9–109.4	13–67	88–154
14	9–73×9–1	3	1	6.1	100.7	1.7–10.8	100.7	3.5–19	140
15	9–74×9–1	9	11	23.0	53.2	15.4–37.6	22.8– 89.4	24–54	65–148
16	9–75×9–1	9	12	11.8	49.6	2.8–25.8	20.5– 71.3	8–47	55–132
17	9–76×9–1	9	5	18.1	59.1	5.0–29.3	47.7– 80.3	12–47	80–93
18	9–77×9–1	16	8	14.1	52.5	0.6–38.2	43.7– 65.8	3–64	59–165
19	9–78×9–1	14	12	12.4	43.2	1.2–27.1	23.2– 49.9	2–61	43–124
20	9–79×9–1	0	21	—	59.3	—	26.8–106.2	—	47–163
21	9–80×9–1	0	10	—	84.0	—	49.2–124.9	—	89–193
22	9–81×9–1	13	12	9.1	58.3	2.0–19.3	32.6–128.3	7–36	50–172
Total	11 segregating	112	101	14.8	57.3	0.6–39.8	20.5–128.3	2–69	41.5–172
	4 not segregating	0	72	—	61.2	—	19.6–124.9	—	37–196

Among the average seed sets for self-incompatible plants in the 11 segregating families, no significant differences were found (analysis 11), but with the self-compatible plants, the differences were significant among both the segregating (analysis V, Table 8) and nonsegregating (analysis VI, Table 8) families.

No single average or maximum seed set separates self-incompatible and self-compatible plants in all 12 segregating families. The differences between families in this regard may be caused in part by modifying factors.

Of further interest were the ranges in both average and maximum seed set within the different families. Distinctly bimodal distributions were obtained for both characters in each of the 11 segregating families, while in the 4 nonsegregating families the distributions approximated those of the self-compatible plants in the segregating families. There were only seven cases of overlapping in distribution of averages between self-compatible and self-incompatible types within families, and there were only three cases of overlapping in the maximum seed set values. It is apparent that under conditions of this sort, using about eight heads per plant, a reliable classification into self-compatible and self-incompatible types can be obtained based on either average or maximum seed set.

When one of the four S_fS_f I_1 plants died and the other three proved to be nonvigorous and sparse-flowering types, a further test for S_fS_f individuals was made. In this case the plants were derived from intercrosses of the original self-compatible F_1 plants or from backcrosses between them and their original self-compatible male parent (Table 6). Altogether, 34 such self-compatible progeny plants were tested by crossing them with plants known to bear two other S factors. With this progeny test, smaller populations were grown and the seed set data were not as satisfactory as those from the first 15 families, but they were good enough to allow classification into segregating and nonsegregating plants. From one type of cross, a 1/1 ratio was expected, while from the other the expected ratio was 2/1. In both cases the obtained segregations fitted the expected according to the X^2 test. Among the 13 S_fS_f plants found in this second series, there

TABLE 6.—*Ratios of homozygous/heterozygous F_1 plants and corrected X^2 for 34 additional plants which were progeny tested.*

Type of cross giving rise to tested progeny	Ratios among S.C.F.$_1$ plants as shown by progeny test				Corrected X^2
	Expected		Obtained		
	Homozygous	Heterozygous	Homozygous	Heterozygous	
$S_xS_f \times S_xS_f \longrightarrow S_xS_f + S_fS_f$	9	9	7	11	0.500
$S_xS_f \times S_yS_f \longrightarrow S_xS_y + S_xS_f + S_yS_f + S_fS_f$	5.3	10.7	6	10	0.2

TABLE 7.—*Frequency distributions and average seed set for 561 plants from 69 families all derived from S_fS_f parents.*

Origin of plants and families		Percentage of plants or families in the following classes of average seeds per head											Total plants or families	Average seeds per head for all plants
		0–10	10–20	20–30	30–40	40–50	50–60	60–70	70–80	80–90	90–100	100+		
Plants with following S_fS_f individuals as parents	9–67	2	7	9	6	9	10	8	9	7	7	27	397	74.7
	9–79	0	8	8	6	9	6	12	7	12	7	26	126	75.5
	9–80	5	0	5	8	11	11	13	3	3	8	34	38	82.6
Total, all plants		1	6	9	6	9	9	9	8	8	7	27	561	75.4
Total, family averages		0	0	1	9	9	13	14	16	12	7	19	69	

were some which may prove more desirable than those found at first.

In regard to the practical utilization of S_fS_f plants in breeding operations, it is important that these plants should transmit both vigor and seed-setting ability to their progeny. Some information on these problems has now been obtained for the F_1 generation. The test used in this connection was made by crossing three S_fS_f plants with self-incompatible individuals selected in regular breeding procedures. Sixty-nine such families, of from 2 to 10 individuals each (average 8.1), have been grown and self-pollinated. The average vigor of the progenies proved to be very good, surpassing in every case the mean of their parents, and in most cases the vigor of the better parent. Likewise, from the standpoint of seed set, the S_fS_f plants imparted a tremendous influence on their progeny. Although the 561 plants showed a very wide range (Table 7), and although the 69 families differed significantly in average seed setting ability (Table 8), the average seed set for all plants was significantly higher than that obtained in any other series in this study (Table 8). No significant differences were found, however, between the averages of the families derived from the three different S_fS_f parents. For all practical purposes the seed set of the F_1 plants was very good. Only 1% of the 561 plants averaged less than 10 seeds per head, and only 1 of the 69 families averaged less than 30.

TABLE 8.—*Analyses of variance for seed set data presented in Tables 1, 2, 5, and 7.*

Analysis No.	Families analyzed	Between		Within		F
		D/F	Mean sq.	D/F	Mean sq.	
	Self-incompatible Plants					
I	1,2,3 (Table 1)	2	76.13	152	106.79	0.71
II	Eleven segregating (Table 5)	10	289.03	101	735.49	0.39
	Self-compatible Plants					
III	1,2,3 (Table 1)	2	1585.88	57	736.40	2.15
IV	4,5,6,7 (Table 2)	3	2374.48	141	485.56	4.89**
V	Eleven segregating (Table 5)	10	859.14	90	343.35	2.50*
VI	Four not segreg. (Table 5)	3	2659.10	68	468.92	5.67**
VII	Sixty nine families (Table 7)	68	7987.64	492	1083.50	7.37**
VIII	Totals III, IV, V, VI, VII	4	44971.19	934	1366.52	32.91**

*Significant; exceeds F for P = .05.
**Highly significant; exceeds F for P = .01.

In connection with the various tests for these different studies, the differences in average seed set among all corresponding families were analyzed and tested for significance (Table 8). In the case of self-incompatible plants, no significant differences were noted in either of the two groups of families which were analyzed. On the other hand, with the self-compatible plants, significant differences

were found in every group of families except the three listed in Table 1. In this latter case, the three families consisted of crosses made in three different ways between the same two parents so there would be no reason to expect that the progenies would show significant differences in self-compatibility if they had been adequately sampled. Since significant differences were found in each of the other four groups of families and between the grand averages for the five groups, it is concluded that modifying factors must have played a very important part in conditioning the amount of selfed seed obtained from self-compatible plants.

DISCUSSION

If the S_f gene is to be utilized as a means of obtaining inbred lines, one of the most important considerations is the ease with which this gene can be introduced into desirable self-incompatible lines. Two possible methods of introduction are apparent, i. e., either from heterozygous or from homozygous plants. Since the former plants are more readily available and generally represent a wider range of germ plasm, it seemed at first that plants of this sort might have advantages. When it was observed, however, that less than one quarter of the plants obtained from crosses using a heterozygous self-compatible plant as male were in turn self-compatible, it was concluded that this would represent too severe elimination in the F_1 generation. The reciprocal cross gave the expected 1/1 ratio, but it is not as convenient to produce, since it means growing more potted plants in the greenhouse.

The second means of introducing S_f, namely, from homozygous plants, was found to be more satisfactory. With the three plants which have been used extensively so far, not only were the resultant F_1 plants very vigorous, but practically all of them set large amounts of selfed seed. On account of this behavior one can grow smaller F_1 progenies in order to select the individuals used to start new inbred lines. There is the problem of locating homozygous plants, but these can be found in both inbred and hybrid progenies, and they can be identified by a simple progeny test.

The method of eliminating the S_f gene, after inbreeding is finished, has yet to be worked out in practice. Many suggestions have been speculated upon for most of the species in which self-compatibility has been found (6), but in very few have large-scale operations proved the practicability of these ideas. If it becomes necessary to inbreed for several generations, some plan such as was suggested for red clover (5) might be necessary in order to preserve some heterozygous plants from which self-incompatibility could be recovered. On the other hand, if inbreeding is to be continued for only a few generations before attempting to combine superior lines, it might be possible to carry a larger number of lines and select only among the heterozygous S_f plants which might remain at the end of the inbreeding.

According to hypothesis, all F_1 hybrids from an S_fS_f parent should be heterozygous for S_f. In the first inbred generation, 50% of the

plants should be heterozygous for S_f, in the second generation 25%, and in the third 12.5%. If sampling were liberal within each line at the end of the second or third inbred generation, it should be easy to detect by a progeny test those plants which were still heterozygous for S_f, and all others could be discarded. If several lines had been carried independently, crosses could be made easily to recover a self-incompatible F_1, and these could be increased vegetatively to be planted as pairs or other combinations under isolation in order to produce hybrids or synthetics on a large scale.

The second and third questions which were investigated in these studies have less relation to the practical methods of using the S_f gene as a tool for inbreeding. These questions concern the relation of S_f to the functioning of its associated alleles when the other factors are present in both the male and female parents of a cross. This situation would only rarely develop in most breeding operations, since the series of multiple oppositional alleles in white clover is very extensive (3). From a theoretical standpoint, however, it was very instructive to learn that the S_f gene in pollen does not influence the behavior of pollen bearing other alleles when the two are mixed on a stigma. And in relation to the action of S_f in the female, it had not been demonstrated previously that it acts as a partially dominant factor when all pollen is the same, whereas it does not prevent the inhibiting action of its associated allele if more than one type of pollen is growing in the pistil.

SUMMARY

After further investigations on the behavior of the S_f gene in white clover, the following conclusions were drawn from four separate lines of study:

1. In a heterozygous S_fS_x plant, the two types of gametes were produced in approximately equal numbers at least following macrosporogenesis, but when pollen from such a plant was placed on a stigma bearing two other alleles the S_f pollen functioned to produce less than one quarter of the resultant progeny.

2. When a heterozygous S_fS_x plant was crossed as male onto a self-incompatible plant bearing S_x, the S_x pollen was inhibited completely despite its association with S_f.

3. In a heterozygous S_fS_x plant used as female, the S_f functioned as a partly dominant factor when all pollen normally would have been inhibited (S_xS_x) permitting some seed set, but the oppositional effect was not disturbed by S_f when only part of the pollen was inhibited (S_xS_y).

4. Following selfing or intercrossing of heterozygous S_f plants, homozygous S_fS_f individuals were obtained in expected frequencies, and they were detected easily by a progeny test. Such homozygous plants may prove very useful in breeding operations since the few tested so far have imparted considerable vigor and good seed setting ability to their F_1 progenies.

LITERATURE CITED

1. ATWOOD, S. S. Controlled self- and cross-pollination of *Trifolium repens*. Jour. Amer. Soc. Agron., 33: 538–545. 1941.
2. ————. Genetics of self-compatibility in *Trifolium repens*. Jour. Amer. Soc. Agron., 34: 353–364. 1942.
3. ————. Oppositional alleles causing cross-incompatibility in *Trifolium repens*. Genetics, 27: 333–338. 1942.
4. ————. "Natural crossing" of white clover by bees. Jour. Amer. Soc. Agron., 35: 862–870. 1943.
5. RINKE, E. H., and JOHNSON, I. J. Self-fertility in red clover in Minnesota. Jour. Amer. Soc. Agron., 33: 512–521. 1941.
6. STOUT, A. B. The genetics of incompatibilities in homomorphic flowering plants. Bot. Rev., 4: 275–369. 1938.

THE EFFECT OF PLOWING UNDER AND THE TIME OF PLOWING UNDER LEGUMES ON THE CONSERVATION OF NITROGEN[1]

J. W. Tidmore and N. J. Volk[2]

ADEQUATE amounts of nitrogen for the maximum production of non-leguminous crops can be added to the soil by plowing under sufficient quantities of summer or winter legumes in the southern United States. However, unless care is taken to plow under the summer legumes at the right time of the year, large amounts of nitrogen released from the decaying legumes may be lost by leaching. High temperatures and moderately high rainfall in the late fall and early winter in this region favor rapid decomposition of organic matter plowed under in the fall. Winter rains then leach the liberated plant food, especially nitrogen, into the subsoil and out of reach of the spring crop.

Mooers (2)[3] found that wheat planted on plots where cowpeas had not been grown, or grown and removed as hay, or grown and plowed under produced yields of 15.5, 16.8, and 22.3 bushels per acre, respectively, for a 20-year period. In a later publication he (3) presented data to show that cowpeas plowed under in the fall resulted in lower yields of corn than where the legume was not plowed under until spring.

In his work with lysimeters, Jones (1) found that the time of plowing under the various kinds of green manure crops was extremely important in terms of nitrogen lost, rate of decomposition of the plant residue, and the effect on the following crop.

The experiment, the results of which are reported herein, was undertaken for the purpose of studying under field conditions the effect of spring and fall plowing under of soybeans on the conservation of the legume nitrogen and on the yields of succeeding crops.

PLAN OF THE EXPERIMENT

Twenty-four 1/600-acre concrete bins were built with side walls extending 18 inches into the ground. The soil within the bins was removed and was replaced with a well-composited Norfolk fine sandy loam. Plot treatments were replicated four times.

The following six cropping systems were used: (a) Corn followed by cotton. The cotton and corn stalks were not removed but were plowed under in the spring. (b) Corn interplanted with soybeans and followed by cotton. The soybeans and corn stalks were left on top of the ground and were plowed under in the spring before the cotton was planted. Cotton stalks were plowed under in the spring before the corn and soybeans were planted. (c) Corn interplanted with soybeans and followed by cotton. The corn stalks and soybeans were plowed under

---

[1]Contribution from the Department of Agronomy and Soils, Alabama Agricultural Experiment Station, Auburn, Ala. Published with the approval of the Director. Received for publication June 2, 1945.

[2]Former Head of the Department, now deceased, and former Head of the Department now Head, Department of Agronomy, Purdue University, Lafayette, Ind., respectively.

[3]Numbers in parenthesis refer to "Literature Cited", p. 1010.

in the fall and cotton was planted in the spring. Cotton stalks were plowed under in the spring before corn and soybeans were planted. (d) Corn interplanted with soybeans and followed by cotton. The corn stalks were left on the ground all winter, but the soybeans were cut and stored in a barn until spring, when they were returned to the soil and plowed under with the corn stalks before the cotton was planted. Cotton stalks were plowed under in the spring before the corn and soybeans were planted. (e) Corn followed by cotton. In the fall of the year, soybeans were cut from another field and put on the plot with the corn stalks and both were plowed under in the fall and cotton was planted in the spring. Cotton stalks were plowed under in the spring before corn was planted. (f) Corn followed by cotton interplanted with vetch in the fall. The vetch was plowed under with the cotton stalks in the spring before corn was planted. The corn stalks were plowed under in the spring before cotton was planted.

The soil placed in the bins was sampled and analyzed for pH and total organic matter before any fertilizer was applied and before any crops were planted. At the end of the experiment, the soil in the bins was sampled again and analyses were made for pH, total N, organic matter, exchange capacity, and exchangeable H, Ca, K, and Mg.

During the first three years the NO_3 content of the soil in the bins was determined at approximately bi-weekly intervals from November 9 to April 3, inclusive.

RESULTS AND DISCUSSION

The yields of seed cotton obtained show definitely (Table 1), that spring plowing under of summer legumes was superior to plowing under in the fall. Approximately 100 pounds more seed cotton per acre was produced when the soybeans were plowed under in the spring. The reason for this is readily seen when the data in Table 2 are studied. It will be noted that nitrification began as early as November and the accumulation of nitrates reached a maximum about the first of December. Winter rains then leached the accumulated nitrates out of the soil, and by February 20 all of the soils contained less than 3 pounds of nitrate nitrogen per acre. By April 3 the soils where soybeans were plowed under in the spring began to accumulate nitrates faster than the soils where soybeans were plowed under in the fall. Thus, the soybeans that were plowed under in the fall in this warm, humid climate became partially decomposed before cold weather, and, consequently, a portion of the nitrogen was lost by leaching. Cutting the soybeans and putting them in a barn over winter was not an improvement over leaving them on top of the ground.

The data in Table 2 show that 25.1 pounds of nitrate nitrogen per acre were found in the soil on December 8 where soybeans were plowed under in the fall. However, that amount is the amount of nitrate nitrogen that accumulated against leaching. The actual amount of nitrate nitrogen produced in the soil and lost by leaching was undoubtedly in excess of 25.1 pounds, because leaching of nitrates was going on simultaneously with the production of nitrates. Apparently, nitrates were produced rapidly to about December 8, then production slowed down considerably until the first of April when it again increased. It is possible, of course, that nitrate production continued at a fairly moderate rate even from December to March, inclusive, but winter rains prevented the accumulation of the nitrates, and, consequently, low readings were obtained for the winter period.

TABLE 1.—*The effect of plowing under and the time of plowing under legumes on the yields of crops and on the chemical composition of the soil.*

Plot No.	Cropping system (2-year rotation)*	Time of turning the legumes	Av. yields per acre for 1933–41 inc.		Condition of the soil at the conclusion of the experiment							
								M. E. per 100 grams of soil				
			Bushels of corn†	Lbs. of seed cotton	Percentage organic matter‡	Percentage total nitrogen	pH§	Exchange capacity	Exchange H	Exchange K	Exchange Ca	Exchange Mg
1	Corn—cotton.............	—	9.5	656	0.84	0.035	5.9	4.12	1.64	0.179	1.83	0.200
2	Corn, soybeans—cotton¶....	Spring	14.4	1086	1.15	0.046	5.8	4.41	1.54	0.215	1.88	0.232
3	Corn, soybeans—cotton¶....	Fall	12.5	994	1.19	0.044	5.9	4.42	1.60	0.234	1.75	0.213
4	Corn, soybeans—cotton‖....	Spring	10.7	1052	1.06	0.045	6.0	4.20	1.55	0.235	1.78	0.208
5	Corn, cotton (soybeans)**...	Fall	14.6	873	0.97	0.036	6.1	4.19	1.51	0.187	1.78	0.210
6	Corn, cotton, vetch††.......	Spring	30.7	862	1.19	0.049	5.7	4.31	1.74	0.210	1.55	0.206

*600 pounds per acre of 0–16–8 were applied in the drill to the cotton and the corn except on plot 6 where vetch received 400 pounds, the corn 200 pounds, and the cotton the regular 600 pounds of the 0–16–8 per acre.

†Corn yields are not reliable because of size of plots (1/600 acre).

‡Soil contained 0.73% of organic matter at the start of the experiment.

§Soil had a pH of 5.8 at the start of the experiment.

¶Soybeans were grown in the corn, not harvested but knocked down in the fall.

‖Soybeans were grown in the corn plot, harvested, stored in a shed during the winter, and then put back on the corn plot in the spring.

**Soybeans were not grown in the corn but were harvested from another field and put on the corn plot in the fall.

‡Vetch was planted in the cotton middles in the fall, turned in the spring and followed by corn.

TABLE 2.—*The effect of turning and the time of turning legumes on the amount of nitrate nitrogen found in the soil from Nov. 9 to April 3.*

Cropping system (2-year rotation)*	Time of turning legumes	Pounds per acre of nitrogen in the form of NO_3 in the soil (av. for 1933–35 inc.)										
		Nov. 9	Nov. 24	Dec. 8	Dec. 21	Jan. 8	Jan. 17	Feb. 3	Feb. 20	Mar. 1	Mar. 16	Apr. 3
Corn—cotton	—	3.5	8.2	11.5	3.9	3.4	2.1	2.0	1.9	2.1	1.8	2.3
Corn, soybeans—cotton†	Spring	2.1	3.9	6.8	3.0	4.9	2.3	2.6	2.4	4.1	2.3	6.9
Corn, soybeans—cotton†	Fall	9.2	11.1	25.1	12.3	12.4	5.7	5.4	2.8	2.8	2.0	3.7
Corn, soybeans—cotton‡	Spring	3.6	6.5	11.4	4.3	4.7	2.6	2.6	2.0	1.9	2.4	6.7
Corn—cotton§	Fall	8.8	10.3	17.8	8.6	6.0	2.1	3.5	2.3	2.4	1.9	3.6
Corn—cotton, vetch¶	Spring	5.1	9.6	16.7	5.0	6.7	1.4	2.0	2.1	2.2	2.1	2.3

*See Table 1 for basic fertilizer treatment.
†Soybeans were grown in the corn, not harvested but knocked down in the fall.
‡Soybeans planted in the corn, harvested, stored in a shed all winter, and put back on the corn plot in the spring.
§Soybeans were not grown in the corn but were cut from another field and put on the corn plot in the fall.
¶Vetch was planted in the cotton middles in the fall, turned in the spring, and followed by corn.

The vetch plot did not produce as much cotton as the soybean plots because the cotton was produced on the vetch residue after a crop of corn had been grown. Likewise, the soybean plots did not produce as much corn as the vetch plot because the corn was produced on soybean residue after a crop of cotton had been grown. It will be observed that the corn yields are extremely low on the soybean plots. It is an established fact that soybeans interplanted in corn will usually cut the yield of corn about half because of competition for water. Thus, no significance should be given to the variations in the yields of corn shown for the different methods of handling the soybeans.

The effect of plowing under the legumes on the chemical composition of the soil is shown by the data in Table 1. It is doubtful if any significance should be attached to the small variation found in exchange capacity, exchangeable H, Ca, and Mg, and pH. It will be noted, however, that growing legumes on the land and plowing them under maintained a higher level of potash in the soil than when legumes were left out of the rotation. These results are in agreement with results reported previously by the Alabama Station (4). Probably the two factors largely responsible for the higher levels of potash found are that (a) the legumes extracted potash from so-called unavailable forms; and (b) legumes prevented the leaching of potash during the rainy winter months (4).

Probably the most important effect of the different rotations on the composition of the soil was the effect on the amount of organic matter found in the soils at the conclusion of the test. Soybeans or vetch increased the organic matter content approximately 60% when the entire legume was plowed under. But, when the legumes were grown on another piece of land and only the tops were applied to the soil and plowed under, the organic matter was increased only 33%. A simple cotton and corn rotation in which all the corn stover and cotton stalks were returned to the soil increased the organic matter 15% in 9 years.

The results for total nitrogen (Table 1) show that where legumes were plowed under the content of total nitrogen was about 30% higher than where no legumes were plowed under.

SUMMARY

This investigation was conducted for the purpose of studying the effect of the time of plowing under legumes on the conservation of the nitrogen in the legumes, the effect on succeeding crops, and the effect on the chemical composition of the soil. Six cropping systems were used in four series of 1/600-acre concrete bins. The results may be summarized as follows:

1. Plowing under soybeans in the spring was superior to plowing them under in the fall because in the latter case nitrogen in the soybeans was lost by leaching during the winter as a result of nitrification during the warm fall months.

2. Soybeans allowed to remain on top of the ground all winter gave just as satisfactory results with respect to conservation of nitrogen as did cutting them and storing them in the barn until spring.

3. The loss of nitrogen by leaching following the plowing under of soybeans in the fall undoubtedly was in excess of 25 pounds per acre.

4. Plowing under soybeans for 9 years had practically no effect on the exchange capacity, exchangeable H, Ca, and Mg, or pH of the soil.

5. Total organic matter was increased about 60% over the 9-year period by plowing under legumes every other year.

6. At the end of the 9-year period, soils on which legumes were plowed under contained about 30% more nitrogen than soils that received no legumes.

LITERATURE CITED

1. JONES, R. J. Nitrogen losses from Alabama soils in lysimeters as influenced by various systems of green manure crop management. Jour. Amer. Soc. Agron., 34: 574-585. 1942.
2. MOOERS, C. A. Effect of liming and green manuring on crop yields and on soil supplies of nitrogen and humus. Tenn. Agr. Exp. Sta. Bul. 135. 1926.
3. ————. Influence of cowpea crop on yield of corn. Tenn. Agr. Exp. Sta. Bul. 137. 1927.
4. VOLK, N. J. The effect of soil characteristics and winter legumes on the leaching of potassium below the 8-inch depth in some Alabama soils. Jour. Amer. Soc. Agron., 32: 888-890. 1940.

SELF- AND CROSS-FERTILITY RELATIONSHIPS IN *LOTUS CORNICULATUS* L. AND *LOTUS TENUIS* WALD. ET KIT.[1]

GINO A. TOME AND I. J. JOHNSON[2]

IN the improvement of plants by controlled methods of breeding, one of the prime requisites is a knowledge of the mode of pollination of the species in question. In general, the majority of the forage crops species are cross pollinated either by wind or by insects. In addition to cross-pollination, many of the forage crops species exhibit varying degrees of self-sterility. In certain cases, particularly among the legumes, the nature of the sterility mechanism has been established. In red clover, *Trifolium pratense* (16),[3] white clover, *Trifolium repens* (1), and sweetclover, *Melilotus officinalis* (7), sterility has been shown to be of the personate (oppositional factor) type. In grasses, however, the exact mechanism of self-sterility has not been established, although a genetic basis has been demonstrated in the case of orchard grass, *Dactylis glomerata* (13).

Among the agronomically important forage crops are found both autopolyploids and allopolyploids. In one species, *Agropyron cristatum*, diploid and autotetraploid strains are commercially grown. In *Bromus inermis* (9) plants with haploid chromosome numbers of 21 and 28 have been found. It would appear, therefore, that forage crops, from a genetic and cytologic standpoint, present a somewhat more complex problem in their improvement than the cereals.

Birdsfoot trefoil has been cultivated for a long time in European countries. In 1898, Brand (2) described 60 species of the genus *Lotus* of which only a few have economic value at the present time. Some of the species, like *L. corniculatus* L., *L. tenuis* Wald. et Kit., and *L. uliginosis* Schkuhr., are perennial, and others, including *L. hispidus* Desf. and *L. angustissimus* L., are annuals.

In the United States, the exact history of the introduction of birdsfoot trefoil is not clear. According to McKee and Schoth (11), *L. corniculatus* was collected as early as 1876 as material for herbariums. Britton (3) described this species in the eastern states in 1907, and Nelson (14) listed *L. corniculatus* among the foreign weeds found in Oregon in 1917. Information on the early introduction of *L. tenuis* is lacking. This species has been repeatedly called the narrow leaf type of birdsfoot trefoil and confused as an agronomic variety of *L. corniculatus*.

Silow (15) in his studies on self-fertility of *Lotus* considered these two species as only one but demonstrated a lack of self-fertility in both the broad leaf and narrow leaf types. Darwin (4) covered some flowers of *L. corniculatus* and found that a few pods were formed but

[1]Journal Paper No. J-1298 of the Iowa Agricultural Experiment Station, Ames, Iowa. Project No. 752. Received for publication June 22, 1945.

[2]Assistant Professor, Institute of Genetics, University of Buenos Aires, Argentina, on leave for graduate study at Iowa State College, and Research Professor of Farm Crops, respectively.

[3]Numbers in parenthesis refer to "Literature Cited", p. 1022.

no seed was obtained by selfing. In a study of the inheritance of cyanogenetic properties of *L. corniculatus* Dawson (5) concluded that this species was an autotetraploid. Cytological studies showed that chromosome pairing at meiosis was usually as bivalents and only rarely as quadrivalents. Dawson summarized the botanical characteristics of several species of *Lotus* together with their chromosome numbers. He confirmed the chromosome number of *L. corniculatus* as 2n = 24 and *L. tenuis* as 2n = 12 among collections made in Britain.

The present investigation was outlined to determine some of the basic factors of significance in conducting a breeding program with *L. corniculatus* and *L. tenuis*. The major objectives were to determine the extent of self- and cross-fertility within and between these two species, to compare these two species from a morphological and cytological standpoint, and to study their possible phylogenetic relationships.

MATERIAL AND METHODS

The plants used in the present investigation were grown from 12 seed lots representing American and European origins. Among the 12 lots of seed, 8 were of the "broad leaf" and 4 were the "narrow leaf" type. In October, 1943, rooted clones from 135 broad leaf plants representing all sources of origin and 35 clones from two typical narrow leaf strains were transplanted to 4-inch pots and moved to the greenhouse. After the clones were well established they were subjected to a 24-hour photoperiod by illumination from sunset to sunrise with 200-watt clear Mazda bulbs. Under this photoperiod the plants bloomed profusely and nearly continuously from January 15 to April 15.

Plants were self pollinated by forcing the stigma and free pollen through the opening at the end of the keel, and gently scarifying the stigmatic surface with the pollen-coated flat end of a toothpick. From three to six florets were tripped on each of three to four umbels. Selfing of each plant was continued over a period of nearly two months to provide a broad sampling of environmental conditions. Self fertility was determined on the basis of the percentage of pods set and also on the basis of the number of seeds per pod.

To determine cross fertility the florets were emasculated by removing the open floral parts with a forceps and withdrawing the free pollen by means of air suction provided by a motor-driven suction pump. On the basis of the consistently low self-fertility (Table 3) open flower emasculation probably introduced only a very small possibility for self-fertilization. Cross pollination was accomplished by applying pollen from a freshly opened flower to the exposed stigma. Sufficient checks were made on pollination technic by selfing following emasculation to be sure that emasculation, *per se*, did not influence seed setting. In all cases, plants selected for crossing were also selfed on approximately the same date to minimize possible confounding of environmental factors with fertility.

The technic employed to double the chromosome number of *L. tenuis* was similar to that previously described by Johnson and Sass (8). Seed was germinated on filter papers in petri dishes until the radicle had elongated to 1 inch. The young seedlings were then oriented on filter papers cut to 2-inch wide strips with the cotyledons just extending beyond the edge. The filter paper strip was then rolled and placed on end in a beaker with sufficient water to moisten the filter paper. After 2 days of growth at room temperature, the cotyledons had elongated to ¾ inch above the filter paper. The roll was then suspended in an inverted position and the cotyledons immersed in an aqueous solution of colchicine. Two concentrations were used, 0.1% and 0.05%, with immersion in each for 3 and 6 hours. The treated seedlings were then carefully rinsed with tap water and transplanted to fine sand in the greenhouse. Three lots of 20 to 25 seedlings were used in each treatment.

Seedling growth was very slow, as is characteristic of *Lotus*, even though the flats were watered periodically with a complete nutrient solution. Two months after transplanting to sand, 19 seedlings with darker green color, broader leaves, and thicker stems were transplanted to soil in 4-inch pots and placed under long

photoperiod. Preliminary examination of autotetraploidy was based on pollen diameters in comparison to normal *L. tenuis*. Final verification was made by cytological counts on root tips of cuttings rooted in sand.

In cytological technic for chromosome counts, the root tips were killed in chrome-acetic acid mixture (Craf II) of the following volumetric formula.

1% chromic acid	30 cc
10% acetic acid	20 cc
U. S. P. formaldehyde	10 cc
Water	40 cc

After a period of 24 hours dehydration was obtained using the Dioxan and N-butyl alcohol series and the material was then imbedded in paraffin following the standard methods. Sections of 10 microns were obtained and stained in iodine-gentian violet.

This technic was used to count the chromosome number of both species and to verify chromosome number of rooted cuttings from colchicine-treated material.

EXPERIMENTAL RESULTS

The data from this investigation will be presented in three parts, *viz.*, cytological and morphological differences between *L. corniculatus* and *L. tenuis*, self- and cross-fertility relationships within and between the two species, and the phylogenetic relationship between the two species.

CYTOLOGY AND MORPHOLOGY

As pointed out in the literature review (5), *L. corniculatus* and *L. tenuis* have been shown to differ cytologically in that the former is probably a tetraploid species with a somatic chromosome number of 24 and the latter a diploid species with a somatic chromosome number of 12. The morphological differences described for *L. tenuis* fit rather closely the characteristics of the commercially designated "narrow leaf" strains of *L. corniculatus* included in this study. To determine if these narrow leaf strains were actually *L. tenuis*, root tips from representative plants were examined cytologically and chromosome counts determined. The counts clearly demonstrate that the commercial designation of the narrow leaf strains is incorrect. The narrow leaf strain had 12 chromosomes in root tips and the broad leaf 24, suggesting that the narrow leaf type is in reality *L. tenuis*. Mitotic figures of the two types are shown in Fig. 2.

The morphological differences between the two species are rather definite. The salient differences in morphology of the leaves, stipules,[4] and flower parts are shown in Fig. 1 and in Table 1.

The most striking difference is the ratio of length to width of the stipules which has given rise to the popular description. The species *L. tenuis* is characterized by a narrow leaflet, subtended by lanceolate stipules, while *L. corniculatus* has broader leaflets with ovate-lanceolate stipules. The ratio of length to width of stipules in the former species was found to be 4.0 and of the latter 1.4. The flowers were found to be 30% longer and 16% wider and the standard 17% wider for *L. corniculatus* in comparison with *L. tenuis*. The shape of the pollen grains is elliptical in both species with diameters 19.8 × 18.0 and 17.5 × 14.6 microns for *L. corniculatus* and *L. tenuis*, respectively.

[4]The stipules have been interpreted also as basal leaflets in Bailey's Manual of Cultivated Plants.

TABLE 1.—*Comparative morphology of stipules and floral parts of L. corniculatus and L. tenuis.*

Characters measured in mm	*L. corniculatus*	*L. tenuis*
Length of stipules	8.1	10.8
Width of stipules	5.8	2.7
Ratio of length to width	1.4	4.0
Length of flowers	13.0	10.0
Width of flowers	11.2	9.7
Ratio of length to width	1.2	1.0
Width of standards	8.6	7.3

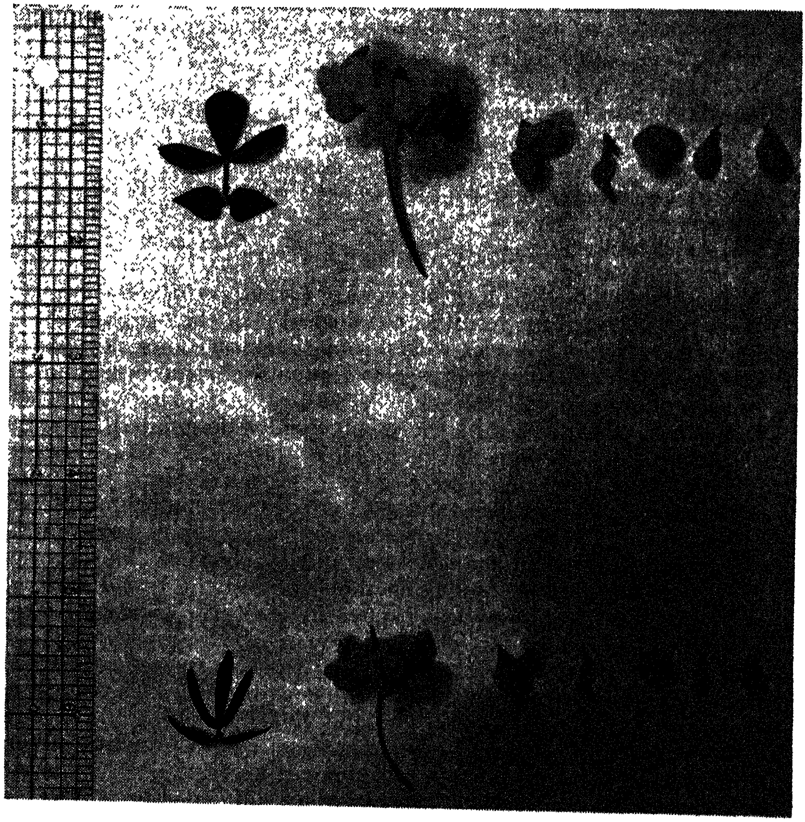

FIG. 1.—Leaf, stipule, and flower characteristics of *L. corniculatus*, upper row, and *L. tenuis*, lower row.

(See Fig. 2.) These differences in leaf, flower, and pollen size are similar to those often obtained when diploids are compared with their autotetraploid derivatives. Since Dawson (5) had demonstrated autotetraploid inheritance in *L. corniculatus*, these morphological comparisons suggested that *L. corniculatus* may have originated from a natural autotetraploid of *L. tenuis*. Although tetrasomic

chromosome pairing occurred only rarely in this species, it is generally recognized, as pointed out by Müntzing (12), that multivalents are not always associated with autopolyploidy.

Plant measurements and notes were made at the end of the first year of growth on a large number of individuals of both species. These data show in general that plants of *L. corniculatus* made a leafier, denser, and wider spread than those of *L. tenuis*. Differences between plants within each of the two species were large in respect to all characters, suggesting considerable genetic variability.

The most common source of variability would be from natural crossing between plants. In this respect, a description of the floral morphology is of interest in relation to adaptability of insect pollination. The keel of the floret in both species of *Lotus* is different from that in other common legumes (*Trifolium* spp., *Melilotus* spp., and *Medicago* spp.) in that the two petals of the keel are fused both at the top and bottom. In the three genera listed above the keel is fused only at the bottom and when insects (primarily bees) collect nectar or pollen the flower is "tripped" when the style and stamens are released from the keel. In *Lotus*, however, the only opening of the keel effective in pollen dissemination is a very small pore at the tip through which pollen and the stigma can be forced by applying pressure on the upper portion of the keel. The pointed tip of the keel is packed with pollen and when the nectar-seeking insects exert pressure on the flower, the anthers and their filaments penetrate further into the tip and pollen passes through the keel opening. By increasing the pressure the stigma also protrudes and thus may become subject to cross pollination.

The bee population in fields of *Lotus* was generally lower than in red clover, sweetclover, or alfalfa. Observations in the field nursery when the plants were in full bloom on warm, clear days showed sufficient honeybees actively collecting nectar to account for cross pollination. This observation agrees with that of Knuth (10). Examination of florets immediately after bee visitation showed that a considerable part of the pollen had been extruded from the tip of the keel. When a honeybee lights on a flower the tip of the keel is near the center of its body thus making a good contact for pollen dissemination. The necessity for cross pollination in seed production will be shown in the following section on self- and cross-fertility relationship.

SELF- AND CROSS-FERTILITY RELATIONSHIPS

Selfs and crosses within species.—The self-fertility of 88 representative plants of *L. corniculatus* and 24 plants of *L. tenuis* was determined in the greenhouse during January, February, and March. The frequency distribution of self-fertility of the plants studied, expressed as percentage pod set and average number of seeds per pod, is given in Table 2.

Among the 88 plants of *L. corniculatus* 78% fell within the 0 to 5% class in percentage pod set indicating a very high degree of self-sterility. The plants of *L. tenuis* were essentially similar to those of *L. corniculatus* in this respect with 75% within the 0 to 5% class. Only a few plants in both species set sufficient pods by self-fertilization to permit self pollination as a means of establishing inbred lines.

TABLE 2.—*Frequency distribution of plants of L. corniculatus and L. tenuis in self fertility as measured by percentage pod set and number of seeds per pod.*

Percentage pod set			Number of seeds per pod		
Class interval	Number of plants		Class interval	Number of plants	
	L. corniculatus	*L. tenuis*		*L. corniculatus*	*L. tenuis*
0–5	69	20	0– .5	61	18
6–10	8	2	.6–1.0	5	1
11–15	4	0	1.1–1.5	2	1
16–20	3	0	1.6–2.0	7	0
21–25	1	1	2.1–2.5	1	0
26–30	0	1	2.6–3.0	5	1
31–35	0	0	3.1–3.5	1	0
36–40	1	0	3.6–4.0	3	1
41–45	2	0	4.1–4.5	3	1
46 +	0	0	4.6 +	0	1
Total	88	24	Total	88	24

As measured by number of seeds per pod, both species were likewise highly self-sterile in comparison with seed set on cross-pollination (Table 4). Obviously for all plants a high relationship would exist between these two values since plants with zero pod set would also have zero seeds per pod. Among 28 plants of *L. corniculatus* that did set pods the relationship between pod set and number of seeds per pod was very poor (r = .320).

Since the nature of the self-sterility is not known, a study was made to check on the possibility of protandry and protogyny. Many self-pollinations were made, using pollen from flowers in the bud stage on well-developed stigmas and pollen from open flowers on stigmas in the bud stage. No differences were found since the percentage of self sterility was the same in all cases. It would appear, therefore, that self-sterility is not due to unequal maturation of the pollen in relation to receptivity of the stigma.

In no cases did selfing, *per se*, take place even though the pollen grains were in contact with the stigma. It would appear, therefore, that the stigmatic papillae must be ruptured to permit pollen germination. If this is the case, bees are effective not only in carrying pollen but also in scarifying the stigma. The need for breaking the film over the stigma to permit pollen germination has been demonstrated in both alfalfa and sweetclover.

These data would support the conclusion that seed set under field conditions is almost entirely due to cross pollination. The observed variability between plants is therefore due to the normal expression of heterozygosity resulting from natural cross pollination. A breeding program with these two species must therefore follow the procedures adapted to self-sterile plants.

Studies on cross-fertility were conducted parallel with those on self-fertility to obtain a comparison of percentage pod set and number

of seeds per pod. Every plant in *L. corniculatus* that had been self-pollinated was crossed with a male parent of the same species chosen at random. Sixteen of the 24 plants of *L. tenuis* were likewise used in cross fertility studies. The data on cross fertility given in Table 3

TABLE 3.—*Frequency distribution of plants of L. corniculatus and L. tenuis in cross-fertility as measured by percentage pod set and number of seeds per pod.*

Percentage pod set			Number of seeds per pod		
Class interval	Number of plants		Class interval	Number of plants	
	L. corniculatus	*L. tenuis*		*L. corniculatus*	*L. tenuis*
0–10	0	5	0–5	7	7
11–20	0	2	6–10	29	3
21–30	2	1	11–15	31	3
31–40	8	1	16–20	15	2
41–50	10	1	21–25	5	1
51–60	13	0	26–30	1	0
61–70	10	0	31–40	0	0
71–80	16	2			
81–90	5	0			
91–100	24	4			
Total	88	16	Total	88	16

clearly show a much higher percentage pod set and number of seeds per pod than that obtained from self pollination. Failure of pod set in cross-fertility was obtained for five plants of *L. tenuis*. Since only four florets per plant were involved in cross pollination, it is not possible to conclude that failure was due to similarity in sterility allels in the male and female plant. Duplication of sterility allels might be expected to occur more frequently in diploid than in tetraploid plants. Unfortunately these crosses could not be repeated to check the data since the plants had passed blooming stage when counts on pod set were made. Further studies are needed to determine the nature of the self-sterility mechanism involved in these species.

A summary of all pollinations within each species given in Table 4 shows the general relationship between self- and cross-fertility. The average self-fertility value for the two species was nearly identical both in percentage pod set and number of seeds per pod. The number of seeds per pod in this summary was calculated from the total pods set and total number of seeds produced. Therefore zero values for pod set do not influence the average seed set per pod. The percentage pod set for *L. corniculatus* was somewhat higher than for *L. tenuis*. These values are different from those normally obtained under field conditions. In the field nursery where both species bloomed profusely, seed setting on *L. tenuis* was observed to be considerably better than in *L. corniculatus*. It is of considerable interest to note that seed setting under controlled cross pollination was very good for the tetraploid species. Such species experimentally produced from di-

TABLE 4.—*Average self- and cross-fertility for all plants of L. corniculatus and L. tenuis.*

Method of pollination	Florets selfed or crossed	Percentage pod set	Number of seeds per pod
	L. corniculatus		
Selfed	1,940	3.50	3.18
Crossed	434	71.65	11.89
	L. tenuis		
Selfed	455	3.29	3.13
Crossed	56	50.00	9.22

ploids are normally low in fertility, although variation between plants in this respect has been demonstrated (6, 8). Apparently *L. corniculatus* has existed as a tetraploid in nature for a comparatively long period of time, and like other natural autotetraploids (tall oat grass, orchard grass, and crested wheat grass) has undergone natural selection for high seed production.

Crosses between species.—Previous investigations reporting crosses between autotetraploid and diploid relatives have almost universally shown a lack of seed formation. In maize a few triploid seeds occasionally are formed. Crosses were made between the two species of *Lotus* to determine if similar results would be obtained with this material. Sufficient reciprocal crosses were made to study the effect of gametophytic chromosome numbers on ovary stimulation. The results from these crosses in comparison with intra-specific crosses are shown in Table 5.

TABLE 5.—*Comparative cross-fertility of inter- and intra-specific hybridization in Lotus as measured by per cent pod set and number of seeds per pod.*

Species	Florets crossed	Percentage pod set	Number of seeds per pod
L. corniculatus × *L. corniculatus*	74	78.2	12.4
L. corniculatus × *L. tenuis*	68	1.2	0.0
L. tenuis × *L. tenuis*	34	66.9	11.7
L. tenuis × *L. corniculatus*	34	61.5	0.0

In these crosses, the same plants were used as female parents with the two species to provide a more direct comparison of cross-fertility. In crosses between *L. corniculatus* × *L. tenuis* there was a very slight amount of stimulation resulting in pod formation, while in the reciprocal pod formation was nearly equal to that from the intra-specific cross. Pods produced from the cross *L. tenuis* × *L. corniculatus* were reduced in size but did not abscise from the raceme. In no cases, however, was viable seed produced in the pods formed from inter-specific crosses. Consequently, it was impossible to determine the chromosome number of the hybrids.

It is of considerable interest to speculate on the probable reason

for differences in pod formation in the two crosses between the species. On the basis of gametophytic chromosome numbers, the extent of unbalance is not as marked in *L. tenuis* × *L. corniculatus* as in the reciprocal. In the former cross, the chromosome number of the stylar tissue is 12 and of the male gamete also 12, while in the reciprocal the chromosome number of the stylar tissue would be 24 and of the male gamete 6. It might appear that some pollen tube growth causing stimulation to pod formation was more favorable when the chromosome number of the stylar tissue and the pollen tubes were the same. From the standpoint of chromosome balance in the egg and sperm cells, the same degree of differentiation would occur regardless of the way in which the species were crossed. In *L. tenuis* × *L. corniculatus* the egg cell would contain one-half as many chromosomes as the sperm cell, while in the reciprocal the egg cell would contain twice as many chromosomes as the sperm cell; in either case a ratio of 1:2 or 2:1. Attempts were made to follow pollen tube growth in the stylar tissue, but the technic could not be sufficiently perfected to permit tracing the pollen tube growth in the style.

PHYLOGENETIC RELATIONSHIPS

From the investigations by Dawson (5) in which tetrasomic inheritance was demonstrated in *L. corniculatus* and from the counts on chromosome numbers of the two species, the question naturally arose as to the origin of *L. corniculatus*. Since these two species resemble each other more closely than any of the other species of *Lotus*, it might be postulated that *L. corniculatus* could be an autotetraploid form of *L. tenuis*. The differences between the two species in leaf characters, flower size, and pollen diameters are in general agreement with those in diploids and artificially induced autotetraploids. If *L. corniculatus* was an autotetraploid of *L. tenuis*, then an experimentally produced autotetraploid *L. tenuis* might resemble the former in leaf and flower characteristics and in pollen diameter. The supposed natural and the induced autotetraploid might also be cross fertile.

To test the validity of this hypothesis, an autotetraploid form of *L. tenuis* was produced by colchicine treatment as previously described. Only one autotetraploid seedling was somatically pure for the tetraploid condition and another seedling had both diploid and tetraploid sectors. The complete autotetraploid arose from young seedlings immersed for 6 hours in 0.1% colchicine and the sectored individual from 6-hour immersion in 0.05% colchicine. It is possible that other autotetraploid seedlings occurred among those grown in greenhouse flats. Preliminary separation was based largely on leaf width—a criterion which proved to be in error.

The autotetraploid *L. tenuis* plant was verified as having $2n = 24$ chromosomes in root tips produced on cuttings. Mitotic figures are shown in Fig. 2. In the method used for inducing chromosome doubling the original root system should be diploid because the hypocotyl was not subject to colchicine treatment. Therefore rooted stem cuttings were necessary to measure the somatic chromosome number of the aerial portion of the plant.

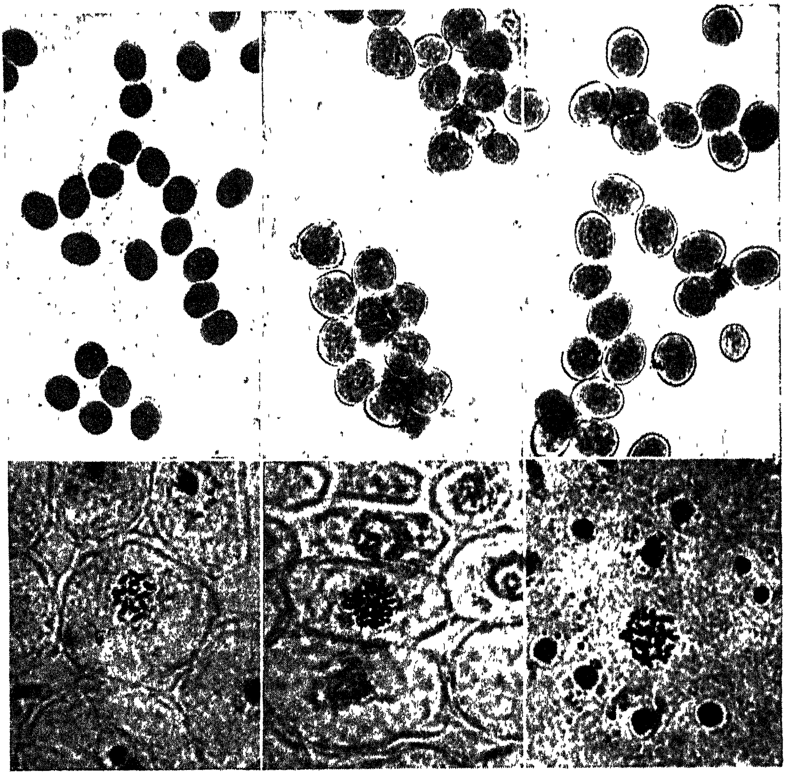

FIG. 2.—*Upper row*, pollen grains × 400, left to right, *L. tenuis*, autotetraploid *L. tenuis*, and *L. corniculatus*. *Lower row*, mitotic cell division in root tips × 1000, left to right, *L. tenuis*, autotetraploid *L. tenuis*, and *L. corniculatus*.

The autotetraploid *L. tenuis* did not resemble *L. corniculatus* in leaflet or stipule shape. Although the leaflets and stipules were broader and thicker than those of *L. tenuis*, the stipules in particular were equally lanceolate as those in *L. tenuis*. The ratio of stipule length to width in the autotetraploid was 3.2 in comparison with 4.0 and 1.4 for *L. tenuis* and *L. corniculatus*, respectively. It should be recalled that stipule shape is one of the most consistent differences between the two species. In flower size, however, the autotetraploid *L. tenuis* was distinctly larger than normal and approximately equal to *L. corniculatus*.

In pollen diameters, the induced autotetraploid closely resembled *L. corniculatus*, but in shape the autotetraploid was distinctly triangular while *L. corniculatus* is elliptical. The comparative diameters obtained from microscopic measurements were 20.0 × 18.7 and 19.8 × 18.0 for the autotetraploid and *L. corniculatus*, respectively. The pollen diameters of normal *L. tenuis* and *L. corniculatus* were previously shown to be distinctly different. Pollen grains of the two species

and of the autotetraploid form of *L. tenuis* are illustrated in Fig. 2.

In the above comparisons, the autotetraploid form of *L. tenuis* resembled *L. corniculatus* in some respects but differed in others (stipule shape). A further study of possible similarity was made on the basis of cross-fertility relationships. Only a few florets were produced which limited the number of crosses that could be made particularly with the autotetraploid as the female parent. The data on cross fertility in Table 6 show a very high percentage of pod set in the cross between *L. corniculatus* × autotetraploid *L. tenuis*, and no pod formation for the few crosses made with the reciprocal or between the autotetraploid and the diploid species. The pods formed in the first cross were normal in size and compared in all respects with those in crosses between plants within *L. corniculatus*. Before threshing the pods it was assumed that seed set was obtained, but as shown in Table 6 no normal seed was present. The pods contained only

TABLE 6.—*Cross-fertility relationships between autotetrapolid L. tenuis, diploid L. tenuis, and L. corniculatus.*

Species crossed	Florets crossed	Pods set	Seeds matured
L. corniculatus × autotetraploid *L. tenuis*....	39	34	0
Autotetraploid *L. tenuis* × *L. corniculatus*...	5	0	0
L. tenuis × autotetraploid *L. tenuis*.........	12	0	0

abortive seeds which were incapable of germination. The percentage pod set in the cross *L. corniculatus* × autotetraploid *L. tenuis* was much different from that between *L. corniculatus* and diploid *L. tenuis* (Table 5), indicating that doubling of the chromosome number had a marked influence on pod formation in this case. The fact that no normal seed was obtained throws considerable doubt on the hypothesis that *L. corniculatus* is an autotetraploid of *L. tenuis*. The data, however, do not entirely eliminate this possibility. If *L. corniculatus* has been established as an autotetraploid in nature for a considerable period of time, as suggested by its high seed production, it may by now have undergone sufficient chromosome change from its possible diploid ancestry to be no longer cross compatible with an experimentally produced autotetraploid derivative of its true diploid parentage.

SUMMARY AND CONCLUSIONS

1. Cytological and morphological studies have demonstrated that the two varieties of birdsfoot trefoil called broad and narrow leaf are probably two different species. The narrow leaf type, designated as *L. tenuis* by Dawson (5) has six pairs of chromosomes and the broad leaf type, designated as *L. corniculatus* has 12 pairs.

2. Self sterility within the two types was measured by means of controlled self-pollination. In both types high sterility was obtained as measured by percentage pod set and number of seeds per pod.

3. A high percentage pod set and large number of seeds per pod were obtained from crosses between plants within each of the two types.

4. Failure in cross fertility was obtained for five plants of *L. tenuis*, but sufficient data are not available to conclude that failure was due to similarity in sterility allels.

5. Complete failure of seed set was obtained in crosses between the two types. Stimulation resulting in pod formation was found in crosses when *L. tenuis* was used as the female parent but not in the reciprocal. These results were explained on the basis of chromosome balance of the two parents.

6. Differences in morphological characters observed in the two species were in general accord with those of diploid and artificially produced autotetraploid plants.

7. To test the possible phylogenetic relationship between the species, the chromosome number of *L. tenuis* was doubled with colchicine. The autotetraploid *L. tenuis* did not resemble *L. corniculatus* in leaf or stipule shape. Similarities of flowers and pollen grains are undoubtedly present. Crosses between the autotetraploid *L. tenuis*, *L. tenuis* and *L. corniculatus* showed a high percentage of pod set in crosses between *L. corniculatus* × autotetraploid *L. tenuis* but in no case was viable seed obtained.

8. Failure to obtain seed set may not be final evidence that *L. corniculatus* could not have arisen as an autotetraploid of *L. tenuis*. Chromosome differentiation after the natural autotetraploid was formed may have sufficiently separated this species from an experimentally produced autotetraploid to render them cross-sterile.

LITERATURE CITED

1. Atwood, S. S. Genetics of cross-incompatibility among self-incompatible plants of *Trifolium repens*. Jour. Amer. Soc. Agron., 32: 955-968. 1940.
2. Brand, A. Monographie der Gattung *Lotus*. Bot. Jahrb. für Sept. Pflanzenges und Pflanzengeograph., 25 (60): 166–232. 1898.
3. Britton, N. L. Manual of the flora of the Northern States and Canada. New York: H. Holt and Co. 1907.
4. Darwin, Ch. The Effect of Cross- and Self-Fertilization in the Vegetable Kingdom. London: John Murray. 1888.
5. Dawson, C. D. R. Tetrasomic inheritance in *Lotus corniculatus* L. Jour. Gen., 42: 49–72. 1941.
6. Fischer, H. E. An investigations of sterility in tetraploid maize. I. Pollen abortion. II. Incompatibilities. PhD. thesis, Cornell University, Ithaca, N. Y. 1939.
7. Gettys, R. E., and Johnson, I. J. The nature and inheritance of sterility in sweet clover, *Melilotus officinalis* Lam. Jour. Amer. Soc. Agron., 36: 228-237. 1944.
8. Johnson, I. J., and Sass, J. E. Self- and cross-fertility relationships and cytology of autotetraploid sweet clover, *Melilotus alba*. Jour. Amer. Soc. Agron., 36: 214–227. 1944.
9. Knobloch, I. W. Morphological variation and cytology of *Bromus inermis*. Bul. Torrey Bot. Club, 70: 467–472. 1943.
10. Knuth, P. Handbook of Flower Pollination. Oxford: The Clarendon Press. 1908.
11. McKee, R., and Schoth, H. A. Birdsfoot trefoil and big trefoil. U. S. D. Ag. Circ. 625. 1941.
12. Müntzing, A. The evolutionary significance of autopolyploidy. Hereditas, 21: 263–378. 1936.

13. MYERS, W. M. Heritable variations in seed set under bag among plants of orchard grass, *Dactylis glomerata* L. Jour. Amer. Soc. Agron., 34: 1042–1062. 1942.
14. NELSON, J. C. The introduction of foreign weeds in ballast as illustrated by ballast-plants at Linnton, Oregon. Torreya, 17 (9): 151–160. 1917.
15. SILOW, R. A. Self-fertility in Lotus spp. Welsh Plant Breed. Sta. Bul., Ser. H, No. 12: 238–240. 1931.
16. WILLIAMS, R. D. Self- and cross-sterility in red clover. Welsh Plant Breed. Sta. Bul., Ser. H, No. 12: 181–208. 1931.

GREENHOUSE AND LABORATORY EXPERIMENTS WITH NITROGEN-BEARING ALUMINUM DROSS AS A FERTILIZER[1]

L. F. RADER, JR., D. S. REYNOLDS, AND K. D. JACOB[2]

DROSSES containing nitrogen are obtained as waste products of the melting and refining of aluminum and aluminum alloys. A survey made by the writers in the early part of 1943 indicated that the monthly production of these drosses in the United States was more than 2,300 tons. In view of the shortage of nitrogen fertilizer materials, which existed at that time, it was considered desirable to investigate the suitability of the dross for agricultural use. Accordingly, greenhouse and laboratory studies were made of the material from a number of plants throughout the country.

COMPOSITION OF DROSS

The melting and refining of aluminum and its alloys requires the use of fluxing agents, commonly the chlorides and fluorides of the alkali and alkaline earth metals (2, 8, 9, 11),[3] which remain largely, if not entirely, in the dross. In addition to impurities derived from the metal charge and from the structural materials of the melting pots and furnaces (2, 11), the dross contains varying quantities of the essential elements of the metal charge itself.

Well-known reactions involving the formation of nitrides through interaction with atmospheric nitrogen (7) occur at the surface of the melt and these nitrides collect in the dross. Though aluminum nitride appears to be the principal nitrogenous constituent of the dross, other nitrides, for example, the magnesium compound, may be present, depending on the character of the melt. Krase, Thompson, and Yee (6) have shown that formation of aluminum nitride by reaction of the metal with atmospheric nitrogen is affected by the presence of other elements and compounds; in particular, the reaction is favorably influenced by small quantities of the chlorides and fluorides of the alkali and alkaline earth metals. Some nitrides, notably those of aluminum and the alkali and alkaline earth metals, react readily with water to form ammonia.

As reported to the writers, the approximate ranges in the percentages of certain constituents of drosses produced at several domestic plants are as follows:

Al metal......	4–20	Zn...........	0.5–2.0
Al_2O_3.........	38–70	Mg..........	0.05–2.50

[1]Contribution from Division of Soils, Fertilizers, and Irrigation, Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture, Beltsville, Md. Received for publication July 25, 1945.

[2]Associate Chemist; Assistant Chemist, deceased; and Principal Chemist, respectively. Grateful acknowledgment is made to W. L. Hill, C. W. Whittaker, and V. L. Gaddy for advice and assistance in certain phases of the investigation, and to A. T. Myers, Division of Fruit and Vegetable Crops and Diseases, for spectrographic analyses of several samples of the dross.

[3]Numbers in parenthesis refer to "Literature Cited", p. 1032.

Si	3–10	Mn	0.10–0.25
Fe	0.75–3.70	Pb	Trace–0.5
Cu	0.9–5.0	Sn	0.05–0.75

In addition, the reports from some of the plants showed Ca, 0.20 to 1.36; Na, 2.75 to 5.40; Cl, 4.25 to 8.20; Ni, trace to 0.15; and unstated small percentages of Cr, Ti, P, K, Bi, and F.

Twenty-one samples of dross were obtained from 14 widely distributed plants operated by seven companies. Material which had not been exposed extensively to the action of atmospheric moisture was requested. The samples as received were crushed and screened through a No. 8 U. S. standard sieve. The coarse fractions ranged from zero to 53.8% of the samples. They consisted practically entirely of free metal and were discarded. The remaining material was ground to pass a No. 60 sieve and was stored in tightly closed bottles.

The samples were analyzed for nitrogen by a special Kjeldahl procedure,[4] with results ranging from 0.43 to 10.35% (Table 1). It will be noted that there was considerable variation in the nitrogen contents of samples from the same plant, as well as of those from different plants of the same company.

TABLE 1.—*Nitrogen content of dross.*

Sample No.	Source of dross		Coarse material in dross, %*	Nitrogen, %†
	Company	Plant		
2189	I	a	9.3	3.64
2190	I	a	13.6	1.58
2191	I	a	10.3	5.51
2192	I	b	3.0	6.43
2193	I	b	1.5	9.32
2194	I	c	0.0	8.43
2195	I	c	0.0	8.58
2196	I	d	7.2	5.07
2197	I	d	53.8	6.00
2198	II	a	0.0	2.03
2199	III	a	0.0	0.58
2200	IV	a	0.0	3.20
2201	V	a	0.0	0.73
2202	VI	a	0.0	10.35
2203	VI	b	0.0	9.68
2204	VI	b	0.0	7.83
2205	VI	c	0.0	0.43
2206	VI	d	0.0	5.06
2207	VI	e	0.0	1.19
2210	VII	a	0.0	3.61
2184	VII	–‡	23.8	6.76

*Material remaining on No. 8 sieve.
†In material passing No. 8 sieve.
‡Unknown.

Six of the drosses were analyzed for a number of constituents other than nitrogen (Table 2). Aluminum metal, aluminum carbide, alumina, calcium, and magnesium were determined by the pro-

[4]Kindly supplied by the Aluminum Company of America, New Kensington, Pa.

cedures of the Aluminum Company of America. Standard methods of analysis, or suitable modifications thereof, were used for the determination of the other constituents. In addition to the constituents listed in Table 2, qualitative spectrographic analyses of samples 2193, 2202, and 2203 indicated the presence of boron, molybdenum, vanadium, and sodium in quantities ranging from "traces" upwards. Antimony, bismuth, and germanium were not detected.

TABLE 2.—*Chemical composition of dross, percentage basis.**

Constituent	Sample No.					
	2193	2194	2196	2202	2203	2206
N, total	9.32	8.43	5.07	10.35	9.68	5.06
P_2O_5	0.07	0.04	0.02	0.01	0.25	0.01
K_2O	0.00	0.00	0.12	0.03	0.04	0.02
Al metal	5.40	8.72	13.54	5.00	8.58	39.00
Al_2N_2†	27.26	24.66	14.83	30.28	28.32	14.80
Al_4C_3	0.34	1.37	0.84	0.52	2.61	1.66
Al_2O_3	43.80	45.80	52.60	44.80	35.10	26.30
Fe	0.85	1.23	2.17	0.68	0.40	0.90
Si	2.26	2.63	4.36	2.41	0.49	1.24
Mg	2.83	3.53	3.05	3.29	8.65	3.14
Ca	0.35	0.37	0.10	0.09	0.11	0.16
Mn	0.12	0.13	0.12	0.21	0.09	0.27
Ti	0.03	0.06	0.07	0.16	0.04	0.05
Cr	0.05	0.05	0.10	0.07	0.05	0.08
Cu	1.84	2.33	3.06	0.64	0.85	1.87
Pb	0.06	0.05	0.07	0.07	0.02	0.00
Ni	0.13	0.41	0.24	0.22	0.12	0.21

*Material passing a No. 8 sieve.
†Calculated from the total nitrogen content.

REVIEW OF LITERATURE

A search of the literature revealed no data relating to the fertilizing value of the nitrogen in aluminum dross, and similar information on aluminum nitride and other nitrides appears to be very scanty.

Hoffman (5) states that Stutzer obtained unfavorable results with finely ground, crystalline aluminum nitride (about 28.5% nitrogen) as a source of nitrogen for oats and mustard. The product decomposed very slowly in the soil. The opinion is expressed, however, that better results would be obtained with amorphous aluminum nitride. Franck (4) reports that the results of his experiments with aluminum nitride containing 8 to 10% of nitrogen show the material to have direct action as a fertilizer, but he gives no data to support this statement. Fichter (3) mentions Franck's investigations and also says that A. Fischer found aluminum nitride to be suitable for fertilizer use. It appears, however, that the details of Franck's and Fischer's studies were not published.

According to Stutzer (10), silicon nitride decomposes so slowly in the soil that it is of no value as a nitrogen fertilizer. Allison (1) found that little or no nitrification of phosphorus nitride occurred in a Susquehanna loam during 75 days.

CONDITIONS OF GREENHOUSE EXPERIMENTS

German millet and Marglobe tomatoes were grown in the greenhouse experiments, the first in 8-inch, bottom-pierced clay pots coated with a water-proof varnish and containing Sassafras fine sandy loam (12 pounds per pot) and the second in 10-inch, side-vented, glazed pots containing Sassafras sandy loam (20 pounds per pot). Both soils were from the Beltsville Research Center, Beltsville,

Md., and neither had been in cultivation for many years. They were passed through an 8-mesh screen.

The glass-electrode pH values of the air-dry field soils, determined on 1:1 soil-water suspensions, were 5.0 and 4.5 for the fine sandy loam and sandy loam, respectively. The respective pH values were adjusted initially to 7.0 and 6.0 by additions of calcium carbonate. During the experiments the moisture content of the soil was maintained at approximately 75% of its moisture-equivalent value by additions of tap water.

The pots received a basal treatment of 0–15–10 fertilizer, in which the P_2O_5 was derived from ordinary superphosphate and the K_2O from potassium chloride. The fertilizer was applied at the rate of 2,000 pounds per acre (2,000,000 pounds of soil) and mixed with all the soil in each pot. In the millet experiment, the nitrogenous materials (dross and ammonium sulfate) were applied at a standard rate of 60 pounds of total nitrogen per acre, whereas the standard rate was 80 pounds per acre in the tomato experiment. In both experiments the nitrogen carriers were mixed only with the top half of the soil in each pot.

Aside from the magnesium in the dross, applications of magnesium were not made to the millet and no adverse effects from the lack of such applications were noted. With tomatoes, on the other hand, some of the plants developed symptoms, within 12 days after transplanting, which proved to be caused by magnesium deficiency. The condition, which was the most pronounced in plants which received nitrogen only in the form of ammonium sulfate, was corrected by application of magnesium sulfate at the rate of 33 parts of magnesium per 1,000,000 parts of soil. To insure freedom from magnesium deficiency, magnesium sulfate was applied to all the tomato cultures. Analyses of six of the drosses used in the experiments showed the presence of 2.83 to 8.65% of magnesium (Table 2).

The millet was planted on April 26, 1943, at the rate of 30 seeds per pot with subsequent thinning to 10 plants. It was harvested on June 13 at the early heading stage. The tomato plants—4 to 5 inches tall, three plants per pot—were transplanted on July 30 and were harvested on September 10 at the very early fruiting stage. The millet experiment was run in duplicate and the tomato experiment in quadruplicate. In both experiments the positions of the pots were rotated within the blocks. The harvested plants (total aerial portions) were dried in a forced-draft oven at about 70°C and were weighed after they had stood overnight at laboratory temperature.

RESULTS OF GREENHOUSE EXPERIMENTS

When the drosses were applied in quantity to supply 60 pounds of nitrogen per acre, the nine samples tested with millet were 1 to 33% as effective in increasing the dry-weight yields as was the same quantity of nitrogen in the form of ammonium sulfate (Table 3). The increases were statistically significant (5% level) with five of the drosses. Similarly, two of the three samples tested with tomatoes at the standard rate of nitrogen application (80 pounds per acre) were, respectively, 2% and 14% as effective as ammonium sulfate, while the yield with the third sample was slightly lower than that obtained with no addition of nitrogen (Table 4). Only one of the drosses had a statistically significant effect on the dry-weight yield of tomato plants.

When nitrogen at the standard rates was supplied equally by ammonium sulfate and dross, the relative yields were not greatly different from those obtained with the half-rate applications of sulfate alone (Tables 3 and 4). In both experiments the yields with the combinations of sulfate and dross were in the same relative order as those with the standard-rate applications of the respective drosses alone. Compared to the half-rate applications of ammonium sulfate alone, two of the three samples of dross used with the sulfate on tomatoes caused slight but significant decreases in yields. This would

TABLE 3.—*Effect of dross on growth of millet.*

Dross No.	Nitrogen source*	Rate of application of dross, per acre, pounds	Average dry weight of plants per pot, grams†	Relative effect of nitrogen on plant growth‡
—	No nitrogen	—	9.7	—
—	Ammonium sulfate	—	20.4	100
2193	Dross	644	10.1	4
2194	Dross	712	10.9	11
2195	Dross	699	9.8	1
2196	Dross	1,183	11.0	12
2200	Dross	1,875	12.6	27
2202	Dross	580	11.7	19
2203	Dross	620	13.2	33
2206	Dross	1,186	12.7	28
2210	Dross	1,662	12.5	26
—	Ammonium sulfate§	—	17.8	76
2194	Dross, ammonium sulfate¶	356	17.2	70
2202	Dross, ammonium sulfate¶	290	17.6	74
2210	Dross, ammonium sulfate¶	831	18.5	82

*Applied at the standard rate of 60 pounds of total nitrogen per acre except as indicated otherwise.
†Difference in average dry weights required for significance at the 5% level is 1.77 grams.
‡Based on 100 as the increase in dry weight resulting from ammonium sulfate at the standard rate of application.
§Applied at the rate of 30 pounds of nitrogen per acre.
¶60 pounds of total nitrogen per acre, derived equally from dross and ammonium sulfate.

seem to indicate the presence in at least some of the drosses of substances having a small depressive effect on plant growth.

Dross reacts with superphosphate with liberation of heat. To deter-

TABLE 4.—*Effect of dross on growth of tomatoes.*

Dross No.	Nitrogen source*	Rate of application of dross per acre, pounds	Average height of plants per pot, cm	Average dry weight of plants per pot, grams†	Relative effect of nitrogen on plant growth‡
—	No fertilizer	—	27.5	4.4	
—	No nitrogen	—	51.7	13.5	
—	Ammonium sulfate	—	64.0	30.3	100
2193	Dross	859	48.3	13.0	3
2202	Dross	774	49.8	13.7	2
2203	Dross	827	54.5	15.9	14
—	Ammonium sulfate§	—	60.8	24.2	64
2193	Dross, ammonium sulfate¶	430	58.3	21.7	49
2202	Dross, ammonium sulfate¶	387	59.8	22.4	53
2203	Dross, ammonium sulfate¶	414	59.8	24.7	67

*Applied at the standard rate of 80 pounds of total nitrogen per acre except as indicated otherwise.
†Difference in average dry weights required for significance at the 5% level is 1.52 grams.
‡Based on 100 as the increase in dry weight resulting from ammonium sulfate at the standard rate of application.
§Applied at the rate of 40 pounds of nitrogen per acre.
¶80 pounds of total nitrogen per acre, derived equally from dross and ammonium sulfate.

mine whether the fertilizing value of the dross is affected by this reaction, several of the samples (Nos. 2193, 2194, 2195, 2202, and 2203) were mixed with superphosphate and potassium chloride. The mixtures were moistened slightly and allowed to stand for 5 days prior to their use at the rate of 60 pounds of nitrogen per acre in pot tests on millet. The relative yields were practically the same as those obtained when the respective drosses, at the same nitrogen rate, were applied separately to the soil.

HYDROLYSIS OF DROSS IN AQUEOUS MEDIUM

The rate of formation of ammonia in aqueous medium was determined for six of the drosses by allowing duplicate 1-gram portions of the material to stand in contact with 200 cc of distilled water in closed flasks at laboratory temperature (about 25 to 30°C) for 1 to 16 weeks. The flasks were shaken for a short time at daily intervals during the first 4 weeks and subsequently at longer intervals.

As shown in Fig. 1, there were wide differences in the rates of hydrolysis of the dross nitrogen to ammonia, especially during the first 4 weeks. The conversion ranged from 3 to 67% in 1 week, from 7 to 85% in 4 weeks, and from 46 to 94% in 16 weeks.

NITRIFICATION OF DROSS

Nitrification tests of three samples of dross (Nos. 2193, 2202, and 2203) were run in the usual manner with 100-gram portions of freshly dug, air-dried Chester silty clay loam from the Esther Scott farm near Sandy Spring, Md., to which were added 1 gram of precipitated

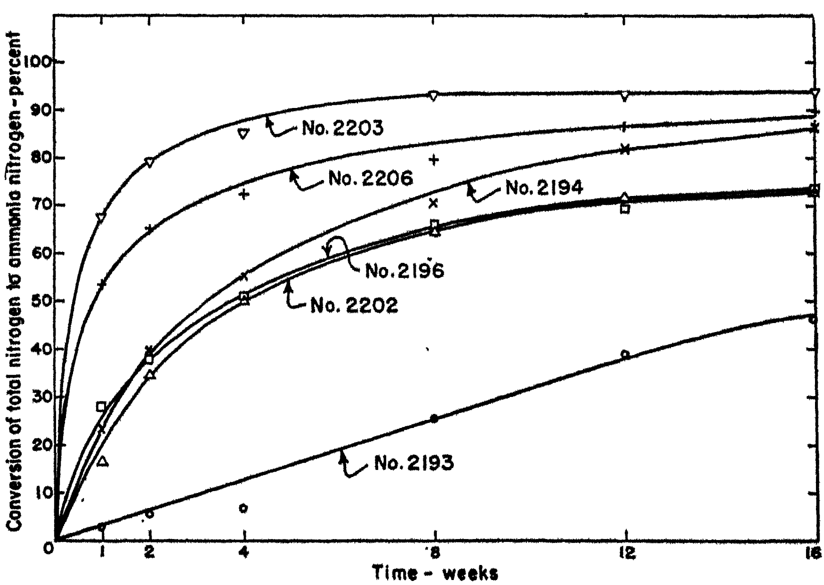

FIG. 1.—Hydrolysis of dross nitrogen to ammonia in aqueous medium.

calcium carbonate and 22 grams of distilled water. Aside from the control cultures without added nitrogen, all but one set of the cultures received 30 mg. of total nitrogen in the form of either dross or C. P. ammonium sulfate. In the exception, the cultures received 60 mg of total nitrogen supplied equally as ammonium sulfate and dross No. 2193. The cultures, contained in wide-mouth bottles loosely fitted with screw caps, were maintained at the initial moisture content and were incubated at 25° to 28°C. Nitrate nitrogen was determined in chlorine-free aqueous extracts of duplicate cultures by the phenol disulfonic acid method. The results, with allowance for the nitrate nitrogen found in the control cultures, are shown in Fig. 2.

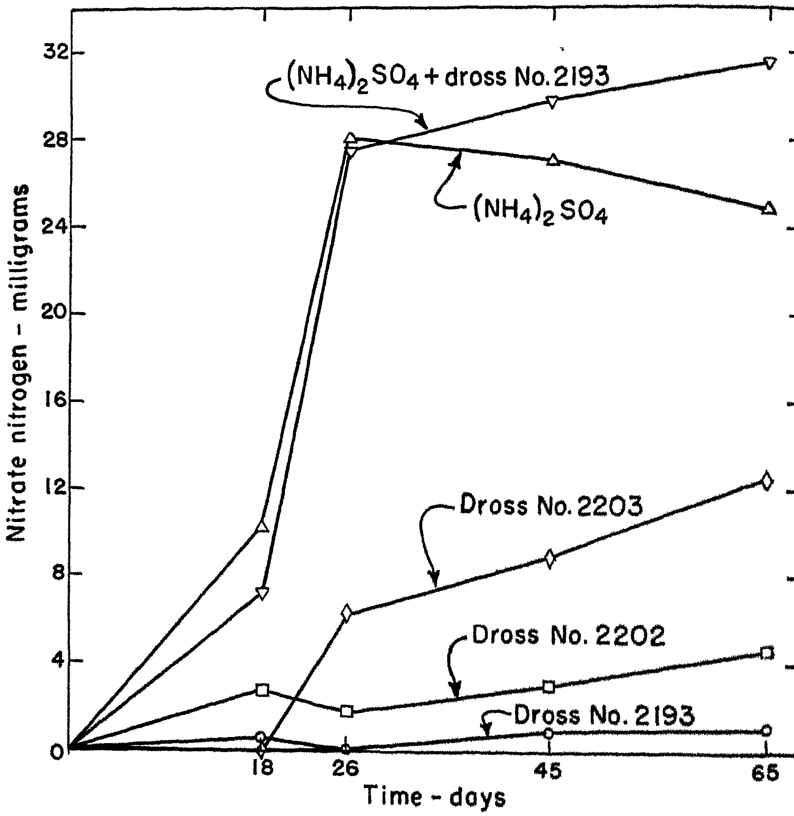

FIG. 2.—Nitrification of dross and ammonium sulfate in 100-gram cultures of Chester silt clay loam.

Under the conditions of this experiment, nitrification of the dross nitrogen ranged from zero to 9% in 18 days, from 3 to 30% in 45 days, and from 4 to 42% in 65 days, compared to 34, 92, and 83%, respectively, for ammonium sulfate alone. Dross No. 2203, which showed the highest and most rapid formation of ammonia in aqueous medium (Fig. 1) and which was more effective than the other drosses in in-

creasing plant growth (Tables 3 and 4), underwent no nitrification in 18 days, but it subsequently exceeded the other two samples in this respect. The results obtained with the cultures containing both ammonium sulfate and dross No. 2193 indicate that at least some of the drosses contain no substances which are harmful to the nitrifying organisms.

RELATION OF PLANT GROWTH TO HYDROLYSIS AND NITRIFICATION OF DROSS

Three of the drosses, which did not differ greatly in nitrogen content but showed rather wide variation in certain other constituents, notably aluminum carbide, silicon, magnesium, and copper, were used in all the greenhouse and laboratory experiments. The results are summarized in Table 5. The effect of these drosses in increasing the

TABLE 5.—*Relation of plant growth to hydrolysis and nitrification of dross.*

Dross		Relative effect of dross on growth of		Proportion of dross nitrogen			
				Hydrolyzed to ammonia in		Nitrified in	
Sample No.	Nitrogen content, %	Millet*	Tomatoes*	28 days, %	56 days, %	26 days, %	65 days, %
2193	9.32	4	−3	7	25	0	4
2202	10.35	19	2	50	65	6	16
2203	9.68	33	14	85	93	21	42

*Based on 100 as the increase in dry weight resulting from ammonium sulfate at the standard rate of application.

growth of millet and tomatoes was, in the ascending order, No. 2193, No. 2202, and No. 2203. Hydrolysis of the dross nitrogen to ammonia in 28 and 56 days, as well as its nitrification in 26 and 65 days, was uniformly in the same order as the results of the greenhouse experiments. It appears, therefore, that the value of dross as a fertilizer is, in general, conditioned principally by the rate and extent of conversion of the dross nitrogen into ammonia and nitrate.

SUMMARY

Dross from the melting and refining of aluminum and aluminum alloys contains nitrogen in the form of nitrides. The nitrogen content of 21 samples of the material from plants throughout the United States ranged from 0.43 to 10.35% and averaged 5.05%.

In greenhouse pot experiments with millet and tomatoes on Sassafras fine sandy loam and Sassafras sandy loam, respectively, the dross was only 1 to 33% as effective in increasing the dry-weight yields as was the same quantity of nitrogen in the form of ammonium sulfate. There were indications that some samples of dross contain substances which may have a small depressive effect on plant growth.

The effect of dross on plant growth was directly related, in general, to the rate and extent of conversion of the nitrogen to ammonia in aqueous medium and to its nitrification in a Chester silty clay loam.

LITERATURE CITED

1. ALLISON, F. E. The nitrification of phosphorus nitride. Jour. Agr. Res., 28: 1117–1118. 1924.
2. FEUER, E. Aluminum alloy scrap — its melting and refining. Metal Indus. (London), 61: 406–408. 1942.
3. FICHTER, F. Über aluminiumnitrid. Ztschr. f. Anorg. Chem., 54: 322–327. 1907.
4. FRANCK, LÉON. Ueber stickstoffaluminium, seine darstellung und sein verhalten. Chem. Ztg., 21: 263. 1897.
5. HOFFMAN, M. Dünger-nova, non curiosa. Mitt. Deut. Landw. Gesell., 26: 386–389. 1911.
6. KRASE, H. J., THOMPSON, J. G., and YEE, J. Y. The fixation of nitrogen as aluminum nitride. Ind. and Eng. Chem., 18: 1287–1290. 1926.
7. MELLOR, J. W. A Comprehensive Treatise on Inorganic and Theoretical Chemistry. VIII. Nitrogen, Phosphorus. 1928. (Pages 97–144.)
8. MICKS, REG. Profitable use of flux. Canadian Foundryman, 16 (11): 20–21. 1925.
9. RUSSELL, H. Slags and fluxes: their composition and use. Foundry Trade Jour., 31: 245–247. 1925.
10. STUTZER, A. Über nitride in ihren wirkungen auf pflanzen. Chem. Ztg., 34: 1015. 1910.
11. THEWS, EDMUND R. Das Schmelzen von aluminum und aluminiumlegierungen in schmelzkesseln. Metallbörse, 19: 425–426; 481–482. 1929.

MORPHOLOGICAL VARIATION IN *POA PRATENSIS* L. AS RELATED TO SUBSEQUENT BREEDING BEHAVIOR[1]

D. C. SMITH AND E. L. NIELSEN[2]

EXTENSIVE investigations in recent years have established the importance of apomictic seed formation in several *Poa* species. Progeny studies of *Poa pratensis* L. plants derived from individual panicles have shown varying degrees of uniformity to exist in morphological characters. Generally, the predominating type has been assumed to be associated with apomictic seed formation while variant plants have been thought to arise as a result of sexual reproduction. It has also been thought that variant or aberrant plants within a progeny would be more likely to produce progenies with higher percentages of aberrants than would the predominating or normal-type plants of the same progenies. The reliability of morphological classification in predicting subsequent breeding behavior is of interest in improvement investigations with Kentucky bluegrass since strains capable of maintaining a practical degree of uniformity might be desired.

Few studies have been reported of progeny breeding behavior beyond the first generation following plant selection. Tinney and Aamodt (4)[3] suggested that the progeny test might well be used as a criterion of the method of reproduction. Myers (2) reviewed the general problem and pertinent literature and presented results of second generation progeny tests to check previous classification. He concluded that such tests were desirable to determine the adequacy of parental classification into aberrant or normal type, though, in general, second generation results served to verify first generation tests. It was also observed that variant-type plants tended to produce higher proportions of sexual plants than sister-parental or normal types.

METHODS AND MATERIALS

The results of the present studies are based upon observation of 45 strains having the following origins:

9 lots from O. A. C. No. 1, Guelph, Canada
6 lots from O. A. C. No 2, Guelph, Canada
15 lots from W. H. Wright, Ottawa, Canada
15 lots from local collections in Wisconsin

---

[1]Contribution No. 202 from the Department of Agronomy, University of Wisconsin, Madison, Wis., in cooperation with the Division of Forage Crops and Diseases, Bureau of Plant Industry, Soils and Agricultural Engineering, U. S. Dept. of Agriculture. Published by permission of the Director of the Wisconsin Agricultural Experiment Station. Received for publication July 26, 1945.

[2]Professor of Agronomy, Wisconsin Agricultural Experiment Station, and Associate Agronomist, Division of Forage Crops and Diseases, Bureau of Plant Industry, Soils and Agricultural Engineering, U. S. Dept. of Agriculture, respectively.
First generation progenies were observed by Dr. O. S. Aamodt, formerly Professor of Agronomy at the University of Wisconsin, and the late Dr. F. W. Tinney, Assistant Agronomist, Bureau of Plant Industry, U. S. Dept. of Agriculture. The writers are indebted to the Statistical Laboratory of the Wisconsin Experiment Station for aid in the statistical calculations.

[3]Figures in parenthesis refer to "Literature Cited", p. 1040.

The types from Guelph and Ottawa, Canada, originated following some previous selection. The first generation progenies from Canadian sources were propagated from bulk lots. Other data reported are based upon individual plant progenies from such lots. Those progenies developed from Wisconsin collections represented random panicles taken in three widely separated local areas of the state.

The numbers of plants in progenies grown varied from 16 to 24 in the different years, though in any one season the number was generally uniform for all progenies. The data obtained were based upon the examination of plants in their second growth year in space-planted nursery cultures. The technics of germinating seeds and establishing individual plants have been described elsewhere (3). The basis for classification of plants as normal or aberrant was relative conformity to the predominating type with respect to appearance when growing in the field. A number of specific characters, including growth habit, aggressiveness, leaf width, color, culm height, vigor, and disease reaction, were considered. Doubtful variants were not included in the calculations. In a larger group of progeny trials these were about 14% of the total number of plants.

Results have been secured for four successive generations. Observations for the first generation were made by F. W. Tinney and O. S. Aamodt who originally established the bluegrass breeding project at Madison, Wis. Subsequent results were obtained by the present writers. By necessity, data for the fourth generation progenies are greatly reduced in scope and accordingly represent only a small sample of the possible segregating families.

RESULTS

Though 45 families having four different origins were studied, consideration of each in detail is impracticable. It is realized, however, that the use of averages may tend to obscure individual progeny trends which might be of considerable interest and that opposite tendencies might counterbalance to a large extent. The results are presented principally as generalizations based upon the average progeny behavior. Individual families of special interest will be discussed. It should be emphasized also that all families were not studied in equal detail. The numbers of progenies for the several generations and the average percentages of normal and aberrant plants for each are shown in Fig. 1. Four families were omitted from the averages shown because they were not grown in all generations. About 570 progenies, including approximately 11,400 plants, were observed. Results of four generations of testing a progeny of a single seed lot are shown in Fig. 2. After the first generation each progeny was grown from a single panicle. An examination of Fig. 2 shows a wide range of variation to exist when progenies from normal and aberrant plants are grown. Also, there appears to be very little similarity among sister progenies.

The high percentage of normal types appearing in the first generation tests is based upon classifications made by Tinney and Aamodt. Individuals vary greatly, no doubt, in their judgments as to similarity of types; however, the average differences between the values for the first and subsequent generations are large.

The frequencies of progenies of entirely uniform or of entirely diverse plants in the several generations are shown in Table 1. It may be noted that the occurrence of uniform or variable progeny is very irregular in proportion of the totals. It is also apparent that relatively few plants produce progenies entirely uniform in type.

TABLE 1.—*Frequencies of completely normal and completely aberrant progenies in several generations of testing of Poa pratensis families.*

Generation	Aberrant percentage		Total progenies
	zero	100	
First	2	0	41
Second	0	9	116
Third	16	21	288
Fourth	4	17	71

While the averages presented in Fig. 1 are of interest in suggesting average breeding behavior, relative differences are important only when considered in light of their significance. The results suggest certain questions, those of principal interest being: (a) Do progenies from plants classified as normal among their sisters tend, as an average, to be more uniform than those from plants classified as aberrant? (b) Do such relations appear to be consistent from generation to generation? (c) Do comparisons within individual families verify the conclusions based upon average behavior?

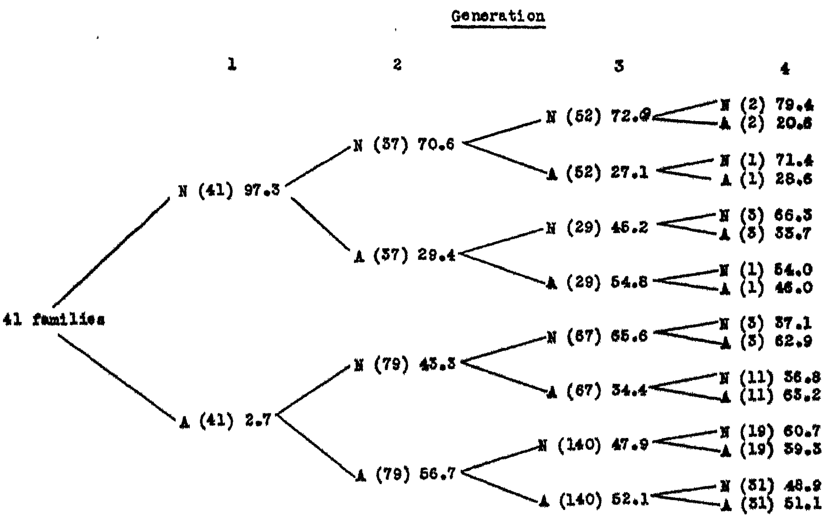

FIG. 1.—Diagrammatic outline of average percentage segregation of 41 progenies of *Poa pratensis* into normal (N) and aberrant (A) types. Number in parenthesis represents total progenies involved in the average.

To provide critical tests of these points, percentages of normal plants were assembled into eight groups based upon their origins and the generation in which they were obtained. The class distinctions have no significance other than to make replicate groups among progenies arising from normal and among those arising from aberrant plants and for different generations. It may be seen by referring to Fig. 1 that eight classes might be made for comparative purposes,

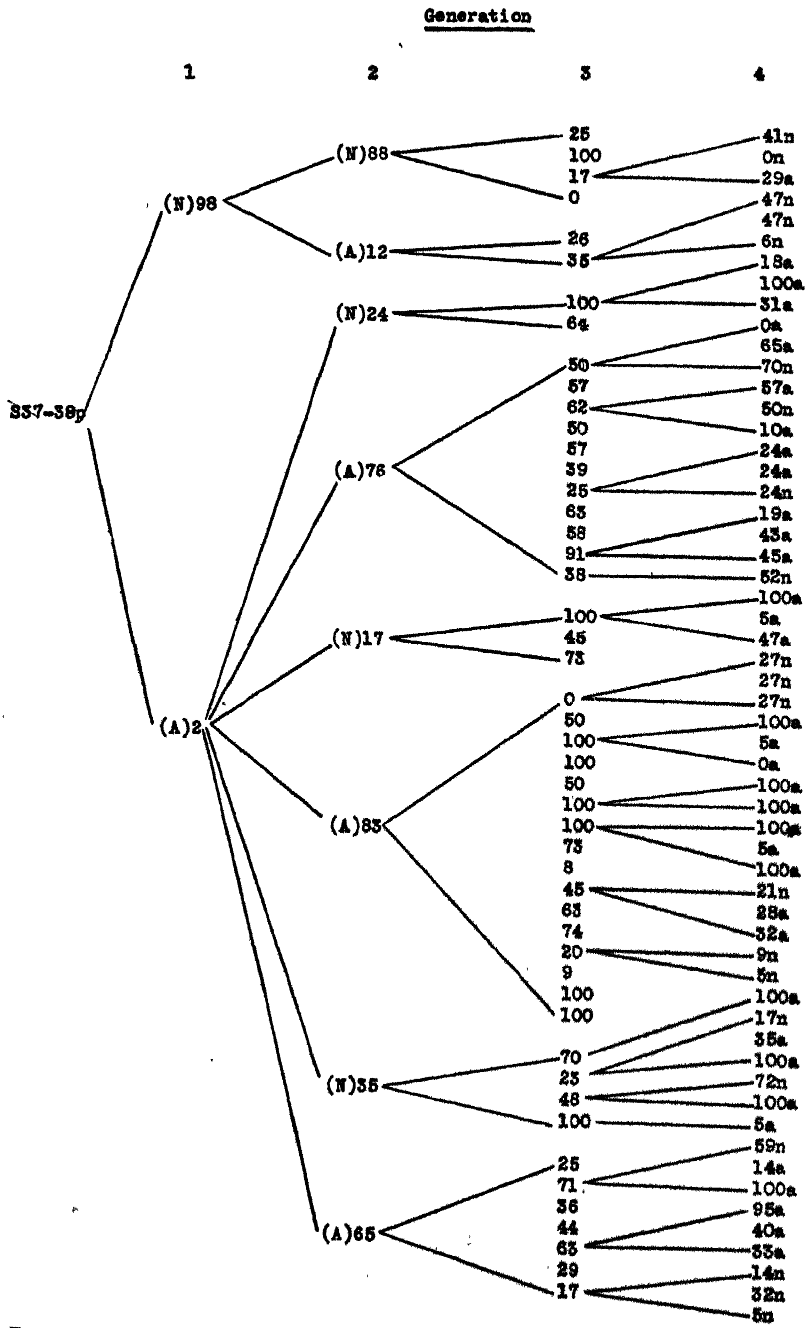

FIG. 2.—Diagrammatic outline of breeding behavior of one family of *Poa pratensis*. N and A represent normal and aberrant percentages (second generation). In generations 3 and 4 figures indicate aberrant percentages. In generation 4

using N and A to indicate the normal or aberrant origin and the numbers 1, 2, 3, or 4 to designate the last two generations. Those are NN12, NNN23, ANN23, and NN34 (all directly from normals) and AN12, NAN23, AAN23, and AN34 (all directly from aberrants). Thus, for example, NNN23 represents third generation data for progenies from normal parents and grandparents and AN34 indicates the fourth generation data from plants aberrant in the immediately previous one, whatever the earlier pedigree may have been. The chi-square test for homogeneity of within-class variances resulted in a value of 12.94 with 7 d. f., and a value of P between .10 and .05. Subsequently, the analysis of variance was utilized to determine whether any differences existed among classes. This is presented in Table 2.

TABLE 2.—*Analysis of variance of several classes of progeny based upon breeding behavior.*

Variation	d.f.	Variance	F
Between			
Between AN and NN	1	36715	41.58**
Within NN	3	2125	2.41
Within AN	3	1014	1.15
Within	562	883	
Totals	569		

**Exceeds .01 point.

TABLE 3.—*Mean percentage values of normal plants for progenies from several groups classified according to breeding behavior.*

Normal from normal			Normal from aberrant		
Group	No. progenies	Percentage	Group	No. progenies	Percentage
NN12	56	60.3	AN12	135	46.4
NN34	28	58.3	AN34	60	45.1
NNN23	53	73.3	NAN23	29	56.8
ANN23	65	62.9	AAN23	144	47.6

The F values in Table 2 indicate that differences within the AN and NN groups are not significant, while those between these groups are highly significant. With a least significant difference based upon the .05 point, all groups directly from aberrant parent plants were significantly lower in percentages of normal progeny than were those from normal sister plants (Table 3).

The data indicate that, on the average, the types reproduced apomictically tend to give rise to progenies more uniform than those from aberrant plants, or that the tendency toward uniformity, is transferred from generation to generation. It is evident, however, that this relationship is not marked and that the average percentage of aberrant plants is high in both types of progenies. There is also

little indication that selection for normal types has served to increase the constancy of the average progeny (Fig. 1).

Sufficient numbers of progeny tests of three families were available to compare the behaviors of individual families. Except for requiring sufficient numbers of progenies, the families were unselected. Third generation data for each were segregated into NN and AN groups. The analysis of variance for families and for these groups is given in Table 4.

TABLE 4.—*Analysis of variance of progenies of three families when classified for aberrant and normal type frequency.*

Variation	d.f.	Variance	F
Between	5	1660	2.20**
Families	2	330	<1
Groups in S37–1p	1	6005	7.98**
Groups in S37–38p	1	437	<1
Groups in S37–55p	1	1197	1.59
Groups NN23 and AN23	1	1973	2.62
Families in NN23	2	2837	3.77**
Families in AN23	2	325	<1
Within	92	753	
Total	97		

** and * exceed .01 and .05 points, respectively.

The F values for comparisons of groups within families indicate that only in family S37-1p did a significant difference exist in the breeding behavior of aberrant and normal plants. The respective mean percentages of normal types were 40.3 and 75.4%, the former being based upon 16 progenies and the latter upon 7. Family S37-38p was highly heterogeneous, five of 35 progenies showing complete variability, i. e., no two plants were morphologically alike. The mean difference between progenies from aberrant and normal plants was not great.

The variance analysis indicated also that the families within the NN group differed significantly in percentage of normal types developed from normal parent plants. The respective mean values for the families as listed were 75.4, 41.2, and 60.2%, only the extreme values being significantly different. Consequently, it seems apparent that families may be expected to vary considerably in breeding behavior in any given trial.

Comparing tendencies of aberrant plants to produce progenies either all aberrant or all normal, 29 progenies from aberrant plants were entirely aberrant whereas 14 progenies from such types were all normal. Thus, an aberrant plant is more often likely to produce completely aberrant offspring. Normal plants produced 100% normal progenies 5 times and one normal plant showed 100% segregation in its progeny. These comparisons show again the relative tendencies for normal and aberrant plants to produce uniform progenies of the mother type.

No families showed complete uniformity for two successive generations or more. With small numbers of plants per progeny much varia-

tion might be expected. Considering 1st, 2nd, and 3rd generation values, certain of the families showed percentages of normal plants as 99, 91, 98; 98, 91, 100; 99, 87, 81; 98, 79, 88; 100, 83, 75; 100, 87, 87; and 99, 96, and 50, respectively. These were the most constant families studied. Nine families showed complete aberrancy for two successive generations. It might be expected that sister aberrant plants within a progeny would produce progenies greatly different in their percentages of normal types. Accordingly, the previous summary of tendencies is not based upon all sister progenies from any parent but only some of those in which the indicated instances agreed with the parental classification.

Considering the 475 averages of the segregations of the second, third, and fourth generation progenies that are summarized in Fig. 1, the average of all segregation was 54.5% normal type. This may be compared with the values in the upper line that approximate 70% for behavior of progenies from normal plants. The present analysis has been developed from studies including disproportionate frequencies of progenies from normal and aberrant plants as Fig. 1 indicates. Accordingly the average percentage segregation, 54.5, is of little significance in representing a random sample of a population of Kentucky bluegrass.

DISCUSSION

It should be noted that in the present work the original parental types have not been grown adjacent to their progenies as a means of checking similarity. Instead the predominant type of the progeny has been designated as the normal, since apomictic reproduction might be expected to be the most reasonable cause of identical individuals arising within a progeny of *Poa pratensis*.

The results of the investigations reported upon have served to verify the observation by earlier workers that aberrant types in progenies predominantly normal are likely to produce progenies relatively high in aberrant plants as compared with progenies from normal sister plants, i. e., those of the predominant type. It has been shown, however, that this is a very general relationship and exceptions occur with sufficient frequency to make the operation of the rule of little value in predicting in a specific manner the probable breeding behavior of any particular family. It is suggested also that the progeny test may be considered only as an analysis of the type of seed production of the parent plant. This would indicate that the phenomenon of apomixis is in itself relatively unstable, or that its inheritance may be somewhat independent of the sexual characters considered in classification of plants as normal or otherwise. Müntzing (1) suggested that apomixis might be controlled by a number of genes operating to allow apomixis, the disturbance of which might result in increased sexual reproduction.

Fair agreement was found by Myers (2) in the relative uniformity of progenies of selected plants compared with that of the parental progenies. Generally similar results were obtained in the present studies. Upon the basis of the results reported, however, it appears that the determination of the method of origin of the parent plant

by a test of its progeny is a procedure of questionable value. The ultimate questions might be (a) how accurate is a morphological classification in establishing relative similarity under field conditions, and (b) may plants identical in general superficial characters possess different apomictic potentialities because of relatively simple genic effects?

Several workers have noted that sexually produced plants in apomictic families were usually lower in vigor than the normal types. This has also been observed by the present writers. Under turf conditions, such weak plants might be submerged by the greater vigor of the normal types and, within reasonable limits, have little relation to mass productivity. Providing a superior selected strain reproduced primarily by apomixis, a fairly high frequency of sexual reproduction would probably not often be noticeable in mass seedings nor would it impair the practical value of the strain for pasture and turf purposes. If sexually produced plants were of equal or of greater vigor and productivity than the parent type, competition or replacement might follow. There is also the possibility that competition among types in ageing sod might greatly reduce an initially high percentage of variability.

SUMMARY

1. Studies of the progeny behaviors of 45 families of *Poa pratensis* were conducted for four generations. The original lots represented selected strains and plants from pasture collections. About 570 progenies, including approximately 11,400 plants, were observed.

2. Progenies from plants previously classified as aberrant were generally higher in proportions of sexual or aberrant types than those from normal sister plants.

3. Selection for normal or apomictic types and their propagation from seed did not appear to be highly effective in the elimination of the tendency toward sexual reproduction.

4. None of the families observed showed complete uniformity of type for two successive generations.

5. Classification of sister plants for morphological similarities and differencess is not closely indicative of the breeding behavior in subsequent generations when specific progenies are considered.

6. Apomictic seed formation in *Poa pratensis* appears to be a relatively unpredictable character.

LITERATURE CITED

1. MÜNTZING, ARNE. Further studies on apomixis and sexuality in *Poa*. Hereditas, 26: 115–190. 1940.
2. MYERS, W. M. Second generation progeny tests of the method of reproduction in Kentucky bluegrass, *Poa pratensis* L. Jour. Amer. Soc. Agron., 35: 413–419. 1943.
3. SMITH, D. C., NIELSEN, E. L., and AHLGREN, H. L. A study of variation of ecotypes in *Poa pratensis* L. In press.
4. TINNEY, F. W., and AAMODT, O. S. The progeny test as a measure of the type of seed development in *Poa pratensis* L. Jour. Hered., 31: 457–464. 1940.

NOTE

SOIL SAMPLING TUBE

THE writers have been working and experimenting with soil sampling equipment for 10 years trying to find a satisfactory type for sampling average field soils for routine chemical and mechanical

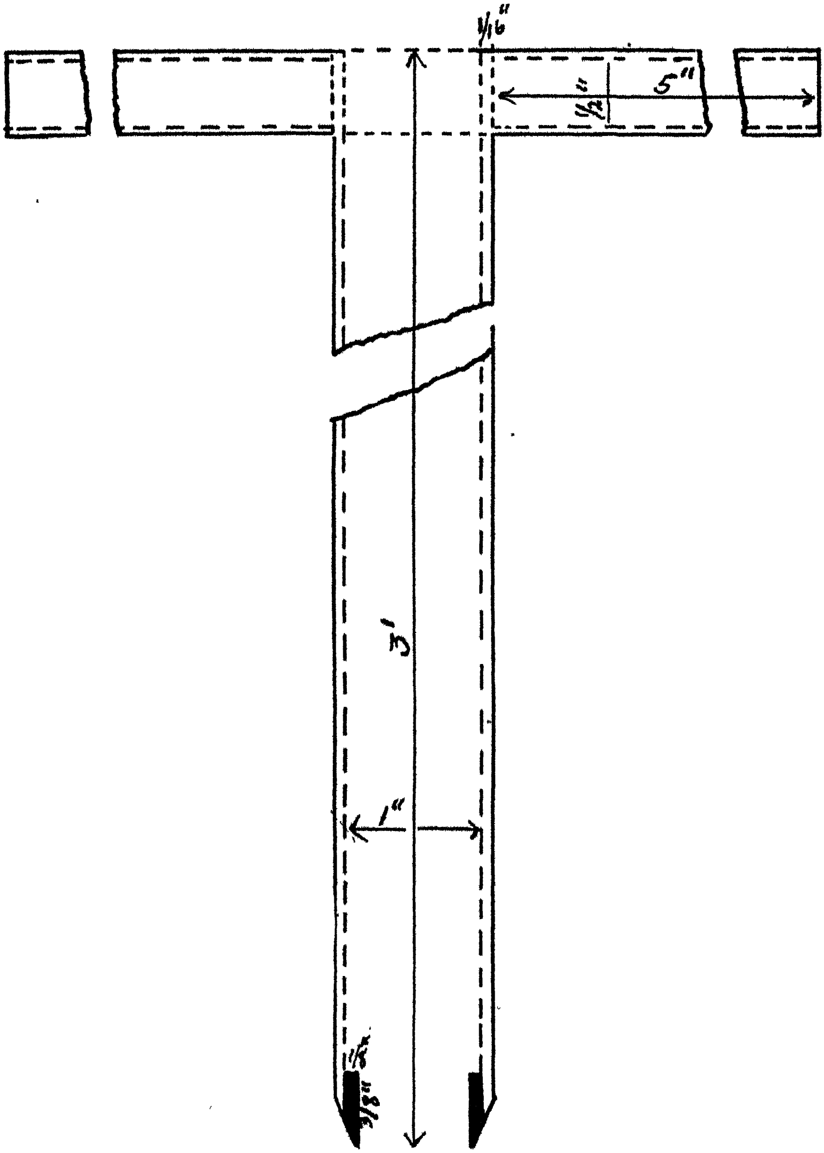

FIG. 1.—Diagram and dimensions of soil sampling tube.

analyses. One of the most satisfactory tubes found to date is represented in the drawing shown in Fig. 1. This tube is made of hard stainless steel or hard brass, the primary feature being that the choked end or drilling point cuts a core of soil just slightly smaller than the bore of the tube. When the tube is inverted the contents slide out. The tube works satisfactorily for moist clay and sandy soils alike. It is not difficult to sink the tube 20 to 30 inches deep into the average soil. One can then lay the soil profile along on a paper for study, if desired. This tube is not entirely satisfactory for stony or extremely dry soils.

The tube is not too difficult to manufacture. A steel core is brazed or welded into the sampling end and hand grips on the other end. This can all be accomplished in a welding shop in a few minutes. The point is then filed or ground down to about a 10 degree angle. If the tube is ground down, care must be exercised to prevent heat from separating the weld. The cost of tubing and welding varies in various sections, but is reasonable.

This tube differs from available tubes in simplicity of construction, differently designed point, and is easy to twist into the soil by hand.—JACKSON B. HESTER AND KENNETH HANKINSON, *Riverton, New Jersey*.

BOOK REVIEW

THE STORY OF LINEN

By William F. Leggett. Brooklyn; Chemical Publishing Co., Inc. 103 pages. 1945. $2.75.

THE history and economic aspects of linen production are traced through the ages in this interesting little volume. The author's skill and style make the book especially readable despite the fact that his viewpoint is that of the textile technologist. Agronomists may deplore the fact that little is presented concerning the details of early flax culture. The chapter on flax might have been strengthened by the inclusion of somewhat more material on the agronomic aspects of the production of the crop. Incidentally, an error crept in when flax seed was described as green in color.

The book should be welcomed as a definite contribution by agronomists who are interested in the utilization of fiber crops. Persons who teach or those who concern themselves with the history of crop growing may readily profit from the fruits of Mr. Leggett's research.

Although the greater part of the book deals with the fabrication of linen and its human implications, other bast fibers such as ramie, hemp, sisal, and jute receive brief treatment under the heading of addenda. The bibliography has merit because it includes sources of information not commonly drawn upon by agronomists. All in all this book is distinctly worthwhile.—H. B. HARTWIG.

AGRONOMIC AFFAIRS

REPORT OF THE JOINT COMMITTEE ON THE NATIONAL SOIL SURVEY

THE Joint Committee on the National Soil Survey was organized in 1942 to discuss and formulate policies having to do with soil survey activities by both Federal and State agencies. Its first report to the Secretary of Agriculture and to the Land-Grant College Association in 1943 was highlighted by the approval of a three-way memorandum of understanding between the Bureau of Plant Industry, Soils, and Agricultural Engineering, the Soil Conservation Service, and the States as well as the approval of the correlation and inspection procedures that were mutually agreed upon by the Soil Conservation Service and the Bureau of Plant Industry, Soils, and Agricultural Engineering. This procedure was approved by the Secretary November 28, 1942. Since the 1943 report, several major developments have occurred that needed attention by the Committee.

(1) The rapid development of the Soil Conservation Districts and the decreases in personnel as a result of the war, created the serious problem of meeting the survey demands without too badly impairing the objective of providing basic information on our soil resources. This problem was given careful consideration by the Committee at its meeting in Washington in August, 1943. At that meeting, semidetailed or "utilitarian" surveys were approved as an emergency measure provided that such surveys "still maintain the standards of quality necessary to ensure that surveys will contribute to the permanent inventory of the nations soil resources."* In these surveys, soils were to be mapped in groups with the thought that such groupings would be adequate for the development of farm plans by the Soil Conservation Service.

A second short-cut procedure, not discussed at this meeting of the Committee, was followed in some areas later in an attempt to meet the demands for mapping. This consisted of the mapping of soils on a farm-to-farm basis, rather than by complete coverage of large areas, such as counties or districts.

(2) The basic information provided by these short-cuts had certain weaknesses for the development of comprehensive farm plans, especially for those involving measures other than erosion control, and for many other agricultural programs.

(3) The mechanisms for carrying out the correlation and inspection procedures gradually broke down.

These developments made it necessary that the Committee attempt to resolve the problems that arose in terms of a more nearly permanent solution. For this purpose, the Committee met in Cincinnati in July, 1944. A rather frank discussion of the problems developed the fact that there were certain fundamental causes for the difficulties that the different agencies were experiencing. These causes were as follows:

---

*See page 4 of minutes of the National Joint Committee on Soil Survey dated August 12, 1943.

1. The three agencies have different objectives in the soil survey work.

(a) The objective of the Bureau of Plant Industry, Soils, and Agricultural Engineering is to study the more permanent and basic properties of soils in both field and laboratory to develop a system of classification, mapping, and interpretation of widest possible permanence and usefulness to all interested in any of the numerous uses, agricultural and otherwise, to which soils may be subjected.

(b) The objective of the Soil Conservation Service is, primarily, to provide soil maps and reports that will serve as a basis for planning on individual farms. The Soil Conservation Service is mainly interested in erosion control and water conservation.

(c) The objective of the States is to provide bases for the research and educational programs within the State, by means of soil classification and productivity studies, and by maps and reports of the soil resources. The States are interested in a wide variety of uses.

2. The funds available to the Bureau of Plant Industry, Soils, and Agricultural Engineering and the States have been inadequate for them to carry their responsibilities in the cooperative soil survey program with the Soil Conservation Service. Part of the funds necessary for correlation and inspection were transferred from the Soil Conservation Service to the Bureau of Plant Industry, Soils, and Agricultural Engineering.

3. The rapid organization of Soil Conservation Districts made it impossible to provide detailed soil maps with sufficient rapidity to meet the needs of the farm planners. The consequent adoption of modifications in legends and procedures designed to accelerate the rate of mapping introduced problems difficult to solve.

This meeting also brought out several suggestions for an amicable settlement of these problems. To permit a more thorough consideration of the proposals by the Committee and to obtain reactions of other members of the interested agencies to these suggestions, further action was postponed until a meeting of the Committee in Washington in August, 1944. These proposals were discussed at length at this meeting, but no decisions were reached. The Committee was called together again at the time of the Land-Grant College meetings in Chicago in October, 1944. Although only a few of the regular members were able to attend this meeting, the group seemed to be getting closer to a solution.

After some interim work, the Committee assembled in Washington on January 10 and 11, 1945. It was not long before a solution was proposed which received the unanimous approval of the Committee. In developing a basic plan of operation it was agreed that the States, the Soil Conservation Service, and the Bureau of Plant Industry, Soils, and Agricultural Engineering should promote a united program of fundamental work adequate to meet the needs and objectives of the different agencies. These fundamental principles were accepted by all:

1. A national coordinated program of soil classification is basic

to the work of all agricultural agencies, both State and Federal, that are concerned with research, education, and action programs dealing with land.

2. A strong nationally coordinated Soil Survey program that will serve the previously mentioned objectives of all agencies is needed.

3. Adequate appropriations must be made available to the Agricultural Experiment Stations of the States and to the Bureau of Plant Industry, Soils, and Agricultural Engineering, as well as to the Soil Conservation Service, if each agency is to carry out efficiently its functions and objectives in the work required in the over-all national program.

In a discussion of the type of survey it was agreed that the survey method is an essential technique for obtaining information necessary for the accomplishment of many objectives, and that these objectives may be of a research, extension, action, or operational nature. It was also agreed that it is desirable to accomplish these objectives as far as possible with one survey. The fact was brought out and agreed upon by all that the soil surveys now being made on a farm unit basis are not accomplishing all important objectives. The present semi-detailed (or "utilitarian") surveys are also not entirely adequate for the development of all necessary programs and are not making the desired contribution to the basic soil classification and mapping program. It was recognized that it is impossible to make basic surveys ahead of all farm planning operations in the more than 1100 districts throughout the nation.

The Committee then agreed that a basic detailed soil survey of at least one representative county (or agricultural part of a western county) in each area or group of counties having similar soils and farming systems would serve as a basis or guide for the farm planning of the entire area. It was agreed that surveys of such representative counties would serve as a temporarily satisfactory compromise between the large immediate needs for detailed surveys and the limited facilities for meeting them.

A plan to make full use of the information thus provided was agreed upon. The farm planning technicians would be trained to recognize the individual soils and their significant characteristics affecting soil productivity, use, and conservation by using the soils information from this representative county. They would use all existing soil information, including available soil maps, in their planning. Then we would have one basic survey for any county. After the first counties were completed, the other counties would be surveyed as rapidly as personnel and funds permitted. Individual farm maps would be made by technicians of the Soil Conservation Service in areas not covered by basic surveys and would be designed for farm planning only. These farm maps would not be a part of the basic soil survey.

It is proposed that the Soil Conservation Service place a collaborating soil scientist with the State Agricultural Experiment Station. This soil scientist would be technically responsible under approved work plans jointly to the Director of the Station and to the

Chief of Research of the Soil Conservation Service, and he would be administratively responsible to the Chief of Research of the Soil Conservation Service. He would be a member of the staff of both the Experiment Station and the Soil Conservation Service.

The collaboratory Soil Scientist would cooperate with the representatives of the State Agricultural Experiment Station in planning and carrying forward Soil Conservation Service interests in a well coordinated program of basic soil surveys for the State. He would cooperate with representatives of the State Agricultural Experiment Station and of the Bureau of Plant Industry, Soils, and Agricultural Engineering in developing legends for the basic surveys and would be technically responsible for the Soil Conservation Service's participation in these surveys. It would be his responsibility, in cooperation with the State representatives, to see that the information from these basic surveys and from other existing surveys is properly used as a guide for farm planning work by the Soil Conservation Service in other parts of the area. Comparable arrangements between the Soil Conservation Service Research Division and the States have been satisfactory.

As under the existing procedure, in the basic soil survey areas the States and the Bureau of Plant Industry, Soils, and Agricultural Engineering shall be responsible for all soils inspection and correlation work involving the mapping of soil types, phases, and related physical features but it will be the joint responsibility of all three cooperating agencies to see that the classification and nomenclature are accurate and that the maps and standards of mapping are adequate for the purposes of the survey. On the basis of these principles the following plan was developed:

1. Procedure to cover the present situation:
   (a) Basic soil surveys will first be made upon a representative county or counties with similar soils and types of farming, as mutually agreed upon between representatives of the State Experiment Station and the Soil Conservation Service and with the concurrence of the Bureau of Plant Industry, Soils, and Agricultural Engineering. The soil classification developed for the representative counties will serve as a standard of interpretation for near-by counties having similar soils and types of farming. As soon as the field work of a soil survey is finished, sufficient copies of the field sheets will be reproduced, as may be mutually agreed upon, to serve agricultural workers in that area. The respective States and the Bureau of Plant Industry, Soils, and Agricultural Engineering will have the primary responsibility for the inspection, correlation, and nomenclature of these basic surveys with the Soil Conservation Service cooperating. When the State has an organized soil survey, the State will have responsibility for technical organization of the basic soil surveys; however, in States where no soil-survey leader is available, the State Agricultural Experiment Station, the Soil Conservation Service, and the Bureau of Plant Industry, Soils, and Agricultural Engineering will, by mutual agreement, designate a man in each State who will

have major technical responsibility for organization of basic soil surveys. When these counties are finished, basic surveys will be made of the other counties of the area with the objective of completing the basic soil survey of the United States as rapidly as possible. Continued participation by the Soil Conservation Service in these later surveys will depend upon their needs.

(b) Since it is necessary for the Soil Conservation Service to have a soil scientist in each of the States where any considerable number of surveys are being conducted, this representative will be given authority to plan jointly with other agencies the technical features of the survey program of the Soil Conservation Service within the State and within that State he will be recognized as the authoritative technical representative of the Soil Conservation Service on surveys.

(c) It will be the responsibility of the Soil Conservation Service Soil Scientist to cooperate with representatives of the State Agricultural Experiment Station in interpreting and utilizing soils information. The planning technicians will utilize not only the basic soil information they gather from the representative county but also all soils information available in the counties in which they will work, including present soil maps. Maps of individual farms will be made by Soil Conservation Service technicians in cooperation with the State Agricultural Experiment Station, under the general supervision of the Soil Scientist of the Soil Conservation Service assigned to the State, and without the regular procedure of inspection and correlation as defined for the basic surveys. These maps will not be considered a part of the basic soil survey of the United States.

If the information provided by the basic surveys of representative counties and by existing soil surveys does not provide an adequate guide for the mapping of individual farms by Soil Conservation Service technicians or for interpretation of individual-farm maps, a reconnaissance soil survey of the area involved, or basic detailed surveys of sample sections, may be made in accordance with the procedure described for basic surveys.

(d) Funds for the correlation and inspection work of the Bureau of Plant Industry, Soils, and Agricultural Engineering, will continue to be provided, for the present, partly by transfer from the Soil Conservation Service to the Bureau of Plant Industry, Soils, and Agricultural Engineering.

(e) Results of the basic surveys will be published cooperatively, as set forth in the existing memorandum of understanding.

(f) Frequent review of and agreement upon the relative scope of the basic soil survey program by the responsible heads of the cooperating Federal and State agencies will be needed to insure an adequate, balanced program.

2. Procedure for a long-time program:

The long-time program would proceed as at present with the exception that more funds would be provided in direct appropriations

NEWS ITEMS

LEWIS T. LEONARD, Bacteriologist of the Division of Soil Microbiology Investigations, U. S. Dept. of Agriculture, with headquarters at Beltsville, Md., has retired from active sevice.

DOCTOR H. R. ALBRECHT has been appointed Assistant Chief of the Department of Agronomy, Purdue University. He came to Purdue in September 1944 after spending 8 years at the Alabama Agricultural Experiment Station where he engaged in plant breeding work.

DOCTOR A. D. AYERS, Associate Chemist, U. S. Regional Salinity Laboratory, Riverside, Calif., has returned to duty after serving for 3 years at the California Institute of Technology as a research assistant on a war research project for the O. S. R. D. Doctor Ayers will be located temporarily at the University of Missouri where he will work in the laboratory of Dr. C. E. Marshall, studying technics developed by Doctor Marshall dealing with the measurement of membrane potentials for the determination of the activity of cations. Before returning to the Salinity Laboratory, he will probably spend 2 or 3 months at the Plant Industry Station at Beltsville, Md., with members of the Division of Soils, Fertilizers, and Irrigation.

DOCTOR M. L. JACKSON, Assistant Soil Chemist in the Department of Soils at the University of Wisconsin, has accepted the position of Soil Chemist at Purdue University. Dr. Jackson will work in the fields of soil chemistry and soil fertility in the Department of Agronomy.

DOCTOR T. B. HUTCHESON, Head of the Department of Agronomy, Virginia Polytechnic Institute, has been appointed Dean of the School of Agriculture, effective January 1, 1946. He will continue to carry the duties of the Head of the Department of Agronomy.

DOCTOR L. A. RICHARDS, Senior Soil Physicist, has returned to duty at the U. S. Regional Salinity Laboratory at Riverside, Calif., after an absence of over 3 years, and will resume his investigations related to the movement and retention of water in saline soils. While on leave, Doctor Richards served as supervisor of the land-amphibious launcher group of the Office of Scientific Research and Development project at the California Institute of Technology. His group

was responsible for the development of a number of rocket launchers used by the Navy, and Doctor Richards spent 6 months in the Southwest Pacific theater as technical observer and field consultant on the use of rockets.

A

RICHARD HALLIGAN has resigned as Assistant Agronomist, Vermont Agricultural Experiment Station and Project Supervisor, Research, Soil Conservation Service, to accept a position as research chemist with Plax Corporation, a plastic firm in Hartford, Conn. His former duties will be assumed about January 1 by Lt. Joseph B. Kelly, now on terminal leave from the Army Air Forces.

A

DOCTOR Y. S. TSIANG recently has resigned his position as instructor in the Division of Agronomy and Plant Genetics, University of Minnesota, and soon will return to China to do corn improvement work for the Chinese national government.

A

H. H. KRAMER, Associate Geneticist on guayule breeding research at Salinas, Calif., has been granted a leave of absence to continue his graduate studies at the University of Minnesota.

A

DOCTOR GEORGE S. BRIGGS has been appointed as an agent (assistant agronomist) in the Division of Tobacco, Medicinal, and Special Crops, Bureau of Plant Industry, Soils, and Agricultural Engineering, U. S. Dept. of Agriculture, and has been assigned to the Lancaster, Pa., laboratory. He was formerly a chemist with the Radio Corporation of America.

A

PROFESSOR A. R. WHITSON, Emeritus Professor of Soils, University of Wisconsin, died suddenly in Madison, Wis., on November 20, 1945, at the age of 75 years. Professor Whitson was a Charter Member and Fellow of the Society. He came to Wisconsin in 1900 to work with Professor F. H. King who left the following year to work on a special project in the Federal Bureau of Soils. Professor Whitson was Chairman of the Department from 1901 to 1939, and retired in 1941. He was one of the pioneers in soil science in this country. Aside from his long and distinguished teaching career in the soils field, he is best known for his early work on nitrates, phosphates, and soil acidity and liming, and his later work in connection with soil erosion and the Wisconsin Soil Survey, which he directed from its inception in 1909 until 1932. He was instrumental in organizing the American Soil Survey Association which later merged with the Soil Science Society of America.

DOCTOR R. W. JUGENHEIMER has been named Associate Professor of Plant Genetics, Department of Agronomy, University of Illinois, in charge of corn breeding. He was formerly in charge of corn breeding at Kansas State College, and more recently Director of Research of Pfister Associated Growers, Inc., El Paso, Ill.

--A--

ACCORDING TO *Science*, Doctor Firman E. Bear, Professor of Agricultural Chemistry at Rutgers University and Chairman of the Department of Soils at the New Jersey Agricultural Experiment Station, addressed the Plant Institute of Ohio State University on December 10 on "Intensive Agriculture in New Jersey, and Some Soil-Plant Problems Related Thereto." He was also guest of honor at a dinner given by the Plant Institute. Doctor Bear was formerly Chairman of the Department of Soils at Ohio State University.

INDEX